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Environmental Assessment

Waste Treatment Facility

Ontario Waste Management Corporation

A provincial crown corporation.

GENERIC PROCESS TECHNOLOGIES
STUDY

REVISED DECEMBER 1982

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Dear Sir

Generic Process Technologies Study

We are pleased to provide the final report of the Generic Process Technologies Study.

The purpose of this study is to identify and evaluate, on a generic level, those technologies which may have applicability to the treatment and disposal of waste in Ontario.

We hope that this document will be of significant value in assisting the reader to appreciate the present availability of the wide range and types of technology options.

Yours very truly

Proctor & Redfern Limited

W. D. Goodings
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WDG:sm
Encl.

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SUMMARY

1. This report presents a compilation of currently available proven technologies which are potentially applicable for the treatment of solid, sludge, and liquid wastes generated in Ontario. The information contained will permit OWMC to choose the appropriate technologies to be included in the waste management system under consideration.

"Special wastes" or "waste" for the purposes of this report is synonymous with liquid industrial waste and hazardous waste and are described as wastes which require special treatment facilities other than waste water treatment or municipal solid waste incinerators or municipal solid waste landfills.

2. The treatment/disposal methods reviewed fall into the following broad categories:

(a) biological treatment
(b) physical/chemical treatment
(c) thermal processing
(d) stabilization/solidification and encapsulation
(e) ultimate disposal

The various processes included in each major category are listed in Table S-1.

3. For each type of treatment/disposal technique reviewed, a brief description including energy requirements, resource recovery potentials, residues and effluents remaining after treatment, associated capital and operating costs, and environmental impacts is given.

4. Since reuse/recycle of wastes will be the subject of a separate study later, reuse/recycle is covered only briefly in this report along with a few typical examples.

TABLE S-1
TREATMENT/DISPOSAL PROCESSES EVALUATED

Biological Treatment Methods

Activated Sludge Process
Activated Sludge Process Using Pure Oxygen
Trickling Filters
Rotating Biological Contactors
Fluidized Bed Wastewater Treatment (Aerobic) Systems
Lagoons (Stablization Ponds) and Aerated Lagoons
Composting
Landfarming
Powdered Activated Carbon - Activated Sludge Process
Aneorobic Digestion
Enzyme Treatment/Mutant or Adapted Microorganisms

Physical/Chemical Treatment Methods

Carbon Adsorption
Resin Adsorption
Centrifugation
Dehalogenation
Electrodialysis
Filtration
Hydrolysis
Ion Exchange
Neutralization
Chemical Oxidation
Precipitation, Flocculation and Sedimentation
Chemical Reduction
Reverse Osmosis
Ultrafiltration
Stripping
Solvent Extraction
Electrolytic Processes

Thermal Processing

Rotary Kiln Incineration
Multiple Hearth Incineration
Evaporation
Calcination/Cement Kiln Incineration
Liquid Injection Incineration
Fluidized Bed Incineration
At Sea/Shipboard Incineration
Molten Salt Incineration
Wet Air Oxidation
PlasmaArc/Microwave Plasma Discharge

TABLE S-1
TREATMENT/DISPOSAL PROCESSES EVALUATED...CONTINUED

Solidification/Stabilization and Encapsulation

Cement Based Processes
Lime Based (Pozzolanic) Processes
Thermoplastic Techniques
Organic Polymer Processes
Glassification

Ultimate Disposal

Secure Landfill
Deep Well Injection
Underground Storage in Geologic Formations
Above Ground Storage

5. In view of practical and economic considerations, the following processes from each of the various major technology categories are most applicable at the present time for the bulk of the wastes generated in Ontario:

   (a) activated sludge treatment and landfarming from biological processes

   (b) filtration, centrifugation, precipitation, oxidation and reduction from physical/chemical processes

   (c) rotary kiln incineration from thermal processes

   (d) secure landfill from ultimate disposal methods.

   Should stabilization/solidification be required for wastes prior to disposition in a secure landfill, mixing the wastes with fly ash or employing lime or pozzolanic based processes are the most suitable approaches.

6. Long-term storage is the only current acceptable method for the management of PCB wastes in view of current environmental legislation.

7. Other treatment/disposal technologies may become attractive in the future as the composition of the wastes received by OWMC becomes better defined or if economics justify the recovery of certain useful constituents or if environmental legislation allows the use of novel techniques for the destruction of PCBs.

1.0 INTRODUCTION

1.1 OBJECTIVES AND SCOPE OF WORK

The purpose of this report is to identify and evaluate liquid industrial waste and hazardous waste abatement, treatment, and disposal technologies on a generic basis. Technologies described in this report are predominantly processes which have been adopted and successfully demonstrated in full-scale applications. However, these methods do not necessarily represent practices to be adopted by the OWMC or the Consultant's recommendations. Treatment technologies far from commercialization and techniques having no immediate applicability to Ontario wastes are not covered in this report.

"Special wastes" or "waste" for the purposes of this report is synonymous with liquid industrial waste and hazardous waste and are described as wastes which require special treatment facilities other than waste water treatment or municipal solid waste incinerators or municipal solid waste landfills.

The technology descriptions and evaluations in this report represent an initial screening of waste management technologies and serve as a 'shopping list' for selection of appropriate special waste management strategies by the Province of Ontario. The six major technology categories described in this study are:

- Waste Abatement, Reduction, Reuse and Recycle
- Biological Treatment
- Physical/Chemical Treatment
- Thermal Processing or Incineration
- Solidification/Stabilization and Encapsulation
- Ultimate Disposal

The text is relatively brief and succinct and was written largely from the sources listed in the Selected Bibliography (Appendix D). The study methodology employed to identify applicable generic technologies is described on Figure C-1 in Appendix C. Briefly, the study involved four steps:

- Determine waste types and quantities in Ontario probably requiring treatment

- Identify the avilable waste treatment technologies

- Select technologies with proven applicability to waste treatment

- Identify proven technologies that may have applicability in Ontario.

The technologies described in Section 3.0 of this report were selected for further evaluation on the basis of the following criteria:

- May have potential applicability to Ontario waste streams
- Proven full scale demonstration.

The study methodology identified in Appendix C consists of the following activities:

- An initial briefing study was held with the Waste Quantities Study project team. The purpose of this briefing was to identify areas of collaboration, discuss respective methodologies and report milestones, and most importantly, to review and evaluate estimates and characteristics of Ontario waste streams.

- A literature review was undertaken to inventory commercial and industrial waste management technologies operating in Canada, United States, Europe and Japan. This activity was supplemented by a series of organized tours to United States and European waste management facilities.

- This initial list of technologies was screened by the Project Team on the basis of demonstrated and immediate full scale applicability to waste management. A few technologies in the developmental stage, particularly those applicable to highly hazardous wastes, were also included; however, technologies offering limited or no potential application or considered unsuitable for wide scale application were eliminated from further consideration.

- Evaluation criteria were developed on the basis of legislative, regulatory, operating, environmental and economic concerns.

- Descriptions for each technology were prepared to assist in the evaluation. This activity required the definition of process and applicability to waste streams without reference to Ontario.

- Technologies were evaluated using the criteria developed earlier in the study. Again, this evaluation was directed to determine the suitability of the technology rather than the applicability of the technology to Ontario wastes.

- Prior to undertaking the assessment of technology applicability to Ontario, further information on liquid industrial waste and hazardous waste generation was required. This activity also required a review of the University of California at Davis (UCD) Waste Classification System. This review resulted in the development of fourteen Waste Stream Description Categories which would be applicable and common to this study and the Waste Quantities Study.

- Technologies which were determined to be suitable in terms of process, management and applicability to waste treatment were then evaluated with regard to technology applicability to Ontario. This evaluation was based primarily on matching suitable generic technologies with Ontario waste streams. It is these technologies that are the subject of this report.

- An implementation framework of various management scenarios was identified. For each of the fourteen waste stream categories, a typical technology system was identified.

1.2 WASTE CLASSIFICATION

The waste classification system developed by the University of California at Davis (UCD Classification System) was used to classify waste streams in this report. The UCD system was also employed in the Waste Quantities Study.

The UCD Waste Classification System identifies liquid industrial and hazardous waste streams in four general categories.

- Inorganic Wastes (liquid and solid)
- Organic Wastes (liquid and solid)
- Sludges
- Miscellaneous Wastes

UCD designation of wastes falling under OWMC mandate along with corresponding Ontario Ministry of the Environment (MOE) classification are depicted in Appendix A..

The matching of waste streams to technologies requires knowledge of the physical and chemical characteristics of the waste. In reviewing the UCD Classification System on this basis, the waste streams were grouped into fourteen Waste Stream Description Categories:

- Organic Sludges and Still Bottoms (no Oils)
- Solvents and Organic Solutions
- Oils and Greases
- Oil/Water Mixtures
- Organic and Oily Residuals
- Heavy Metal Solutions and Residuals
- Miscellaneous Chemicals and Products

- Paint and Organic Residues
- Aqueous Solutions with Organics
- Anion Complexes
- Sludges and Inorganic Residuals
- Pesticides, Herbicides and Wastes
- PCB Wastes
- Clean-Up Residuals

Identifying techniques which may have applicability to Ontario is based on the fourteen Waste Stream Categories. However, when describing and evaluating the applicability of treatment technologies to various waste streams, the three digit UCD classification is used.

1.3 WASTE QUANTITY ESTIMATES

Evaluation and selection of applicable generic technologies were based on estimated wastes generated in the Province of Ontario.

The Waste Quantities Study quantifies waste generated by industry in Ontario without reference or credit to waste currently being treated, recycled, reused, reclaimed or disposed and does not identify waste which requires immediate treatment by OWMC.

1.4 GENERIC WASTE MANAGEMENT TECHNOLOGIES

Background

A large number of process technologies are available for application in a liquid industrial waste and hazardous waste management system. Among these are technologies which have been demonstrated commercially, development projects that have small and large scale application, and technologies with and without operational history. Generally, these technologies can be grouped into six generic process categories:

- Waste Abatement, Reduction, Reuse and Recycle
- Biological Treatment
- Physical/Chemical Treatment
- Thermal Processing
- Solidification/Stabilization and Encapsulation
- Ultimate Disposal.

This study reviews technologies which may have a potential application to waste management in Ontario. Each of these technologies are described qualitatively in Section 3.0 of this report according to the following format:

- **Process Description:** an overview of the technology, including theory and application.

- **Technology Flow Diagram**

- **Waste Inputs:** description of the influent waste streams identified by the University of California at Davis (UCD) Waste Classification System.

- **Effluents and Residuals:** description of the products and waste streams, including residue handling requirements.

- **Implementation, Reliability:** description of technical feasibility, including proven nature of technology.

- **Process Application:** description of current waste management applications as well as future potential.

- **Economic Factors:** an overview of comparative general capital and operational/maintenance costs, where available were documented from existing literature. Best estimate of current (circa 1980) costs in U.S. dollars were identified and will require updating prior to selection of technology.

- **Energy Requirements:** description of power demands and energy intensity of application.

- **Resource Recovery Potentials:** an overview of materials recovery potential.

- **Environmental Factors:** an overview of potential environmental threats posed by the product and process residues.

- **Institutional Considerations:** description of regulatory and possible licensing considerations.

Waste Abatement, Reduction, Reuse and Recycle

Waste abatement, reduction, reuse, and recycle operations represent an approach for reducing the capacity requirements for waste treatment and disposal facilities. At-source process modifications, including the implementation of low-waste industrial processes to replace 'waste intensive' technologies, improved housekeeping practices and waste concentration technologies, can be applied to reduce the quantity of wastes generated. The direct reuse of a waste stream as a process raw material can be approached through plant modification or waste exchange organizations. Reprocessing technologies (such as waste oil refining) can be adapted to reclaim some value from waste streams as a part of a waste recycle or recovery program.

Biological Treatment

Generic biological processes discussed in this report include:

- Activated Sludge
- Activated Sludge (Pure Oxygen)
- Trickling Filters
- Rotating Biological Contactors
- Fluidized Bed Aerobic Treatment
- Aerated Lagoons/Stabilization Ponds
- Composting
- Landfarming
- Powdered Activated Carbon - Activated Sludge
- Anaerobic Digestion
- Enzyme Treatment

Most biological processes employ a mixed population of micro-organisms to convert organic contaminants to less toxic substances through a series of reactions. The organic wastes, in part, supply the nutrient requirements of these micro-organisms. The complexity of the waste's chemical structure determines the biological ease of acclimation and the degree of waste degradation that can be attained. The object of a biological treatment system is to achieve optimum degradation of organic wastes under controlled conditions.

Physical and Chemical Treatment

Physical/chemical treatment technologies act to alter or transform the physical and/or chemical nature of a waste stream. Physical treatment technologies generally separate components of the waste stream or change the physical form of the waste without altering the chemical structure of its constituents. Chemical treatment technologies alter the chemical structure of the waste constituents to produce a less-hazardous residue or to render the wastes innocuous. Generally physical/chemical treatment processes fall into three basic categories:

- Phase Separation
- Component Separation
- Chemical Transformation

A total of 17 physical/chemical treatment technologies are described in this study. The physical treatment processes that are discussed and evaluated for their potential applicability to waste management include:

- Carbon Adsorption
- Resin Adsorption
- Centrifugation
- Electrodialysis
- Filtration
- Reverse Osmosis
- Stripping
- Ultrafiltration
- Solvent Extraction

The chemical treatment technologies that are evaluated include:

- Chemical Dehalogenation
- Hydrolysis
- Ion Exchange
- Neutralization
- Oxidation
- Reduction
- Precipitation
- Electrolytic Processes

Thermal Processing

Thermal processing technologies, commonly referred to as thermal oxidation, utilize elevated temperatures to change the chemical, physical or biological character or composition of a special waste stream. Thermal processing systems generally achieve volume reduction and detoxification of the waste stream and in some situations can be applied to achieve energy and materials recovery. Thermal processing currently is one of the most important waste management options.

A wide variety of thermal processing technologies are available for application in waste management, and a few technologies are in the advanced development stage, providing potential for near future application. Ten thermal processing technologies are discussed and evaluated in text, including:

- Rotary Kiln
- Multiple Hearth
- Evaporation
- Calcination/Cement Kiln
- Liquid Injection Incineration
- Fluidized Bed Incineration
- At Sea/Shipboard Incineration
- Molten Salt Incineration
- Wet Air Oxidation
- Plasma Arc/Microwave Plasma

Solidification/Stabilization and Encapsulation

Solidification and stabilization techniques improve the handling and physical characteristics of the waste stream, decrease the surface area for pollutant transfer, limit the solubility of the waste or chemically fix the hazardous constituents of the waste stream. Encapsulation techniques isolate the waste by surrounding it with an impermeable and chemically inert material.

Five solidification/stabilization and encapsulation treatment technologies are evaluated in this report:

- Cement-Based
- Lime-Based Pozzolanic
- Thermoplastic
- Organic Polymer
- Glassification

Process applicability and waste compatibility are important aspects in the selection of solidification/stabilization and encapsulation technologies. Economic decisions justify waste solidification only when hazardous wastes are produced in large volumes.

Ultimate Disposal

Ultimate disposal technologies are designed to provide a final repository for waste streams. These disposal technologies do not destroy contaminants but are designed to ensure that the contaminants are contained for an indefinite time period. Ultimate disposal represents a waste management option that has application to waste streams not amenable to other reuse/recovery or treatment processes or to the residuals from treatment, thermal processing and stabilization operations. Ultimate disposal will probably be a part of a waste management facility since most waste treatment and incineration processes produce a waste residual stream that must be handled and disposed.

Four ultimate disposal technologies are evaluated in Section 3.4 of the report:

- Secure Landfill
- Deep Well Injection
- Underground Storage
- Above Ground Storage

2.0 APPLICABILITY OF TECHNOLOGIES TO ONTARIO WASTE

2.1 INTRODUCTION

This section presents a preliminary review of the potential applicability of generic process technologies on the basis of waste generation in Ontario along with an implementation framework or system.

None of the technologies discussed in this report, or processes thought to have potential applicability in the near future, can fully treat all the various types of waste streams produced in the province. As a matter of fact, even one particular waste stream cannot be adequately treated in most cases by a single process. Therefore, the 'implementation framework' should be based on the optimal mix of individual technologies to effectively treat and dispose of liquid industrial waste and hazardous waste.

Consequently, for each of the Waste Stream Description Categories consideration has been given to:

- Potential generic process technologies for the treatment and/or disposal of that waste stream.

- Description of an 'implementation framework' for one or more waste streams.

2.2 POTENTIAL TECHNOLOGY APPLICATION

Table 2-1 summarizes the results of the study team's selection of technologies which presently appear to best match Ontario waste streams. Briefly, the following observations can be made:

TABLE 2-1

POTENTIAL APPLICATION OF WASTE MANAGEMENT TECHNOLOGIES TO ONTARIO WASTE STREAM CLASSES*

Waste Stream Description Categories	UCD Waste Classification	Waste Form	Recovery/Reuse	Biological Treatment	Physical/Chemical Treatment	Thermal Processing	Stabilization/ Solidification	Ultimate Disposa
Heavy Metal Solutions and Residuals	111, 112, 113, 121, 122, 123, 131, 132, 133, 141, 142, 143, 144, 244, 251, 431, 433, 445, 511	Liquid, sludge	- Acid recovery (1) - Metals recovery (1,2)	-	- Centrifugation (1,2) - Filtration (1,2) - Neutralization (1) - Oxidation/Reduction (1) - Precipitation (1)	-	- Cement Based (2) - Lime Pozzolanic (2)	-Secure Landfill(2)
Miscellaneous Chemicals and Products	145, 152, 243 245, 416, 513	Liquid, sludge, solid	- Waste Exchange (1,2,3)	-	- Centrifugation (1,2) - Filtration (1,2)	-Rotary Kiln (1,2,3)	- Cement Based (2) - Lime Pozzolanic (2)	-SecureLandfill(2,3) -Deep Well Injection (1)
Paint and Organic Residuals	254, 258, 262, 454 455	Liquid, sludge, solid	-	-	- Filtration (1,2) - Centrifugation (1,2)	-Rotary Kiln (1,2,3)	-	-SecureLandfill(2,3)
Organic and Oily Residuals	282, 284, 285, 286, 287, 288; 289, 447	Liquid, sludge, solid	- Oil Recovery (1)	-Landfarming (1,2,3)	- Centrifugation (1,2) - Filtration (1,2)	-Rotary Kiln (1,2,3)	-	-SecureLandfill(2,3)
Organic Sludges and Still Bottoms (no oil)	247, 248, 252, 263, 446	Sludge, solid	-	-Landfarming (2,3)	- Centrifugation (2)	-Rotary Kiln (2,3)	-	-SecureLandfill(2,3)

* In categories where the waste streams are in more than one physical form - i.e., liquid, sludge, solids - the following code is used to indicate appropriate treatment/disposal:

TREATMENT/DISPOSAL CODE:

1. SUITABLE FOR LIQUIDS
2. SUITABLE FOR SLUDGES
3. SUITABLE FOR SOLIDS

TABLE 2-1 (CONTINUED)

POTENTIAL APPLICATION OF WASTE MANAGEMENT TECHNOLOGIES TO ONTARIO WASTE STREAM CLASSES*

Waste Stream Description Categories	UCD Waste Classification	Waste Form	Recovery/Reuse	Biological Treatment	Physical/Chemical Treatment	Thermal Processing	Stabilization/ Solidification	Ultimate Disposal
Oils and Greases	281	Liquid	- Oil Recovery	-Landfarming	- Stripping - Filtration	-Rotary Kiln -Calcination/ Cement Kiln -Liquid Injection	-	-
Clean Up Residues	512, 521, 528 531	Solid	- Spilled Material Recovery	-Landfarming	-	-Rotary Kiln	- Cement Based - Lime Pozzolanic	-Secure Landfill
Oil/Water Mixtures	283	Liquid, sludge	- Oil recovery (1)	-Landfarming (1,2)	- Centrifugation (1,2)	-Rotary Kiln (1,2)	-	-Secure Landfill (2)
Solvents and Organic Solutions	211, 21[illegible], 213, 214, 215, 216, 217, 221, 222, 223, 224, 225, 226, 227	Liquid	- Solvent and Metals Recovery - Waste Exchange	-Landfarming	- Resin Adsorption - Carbon Adsorption - Chemical Oxidation - Precipitation, floculation, sedimentationn - Stripping	-Rotary Kiln -Calcination/ Cement Kiln	-	-
Aqueous Solutions with Organics	254	Liquid, Sludge	- -	-Activated Sludge (1) -Landfarming (1,2)	-	-	-	-Secure Landfill (2)

* In categories where the waste streams are in more than one physical form - i.e., liquid, sludge, solids - the following code is used to indicate appropriate treatment/disposal:

TREATMENT/DISPOSAL CODE:
1. SUITABLE FOR LIQUIDS
2. SUITABLE FOR SLUDGES
3. SUITABLE FOR SOLIDS

TABLE 2-1 (CONTINUED)

POTENTIAL APPLICATION OF WASTE MANAGEMENT TECHNOLOGIES TO ONTARIO WASTE STREAM CLASSES*

Waste Stream Description Categories	UCD Waste Classification	Waste Form	Recovery/Reuse	Biological Treatment	Physical/Chemical Treatment	Thermal Processing	Stabilization/ Solidification	Ultimate Disposal
Anion Complexes	146, 147, 444	Liquid, sludge	- Metal	-	- Filtration (1,2) - Oxidation/ Reduction (1) - Centrifugation (1,2) - Ion Exchange (1)	-	-	-Secure Landfill (2) -Above Ground Storage (2)
Sludges and Inorganic Residuals	151, 165, 167, 417, 441, 443,	Solid, sludge	- Metal	-	- Centrifugation (2) - Filtration (2)	-Rotary Kiln (2,3)	- Cement Based (2,3) - Lime Pozzolanic (2,3)	-Secure Landfill (2,3)
Pesticides, Herbicides	241	Liquid, solid sludge	-	-Activated Sludge(1) -Powdered Activated Carbon-Activated Sludge(1)	- Carbon Adsorption (1) - Resin Adsorption (1) - Ozonation (1) - Centrifugation (1,2) - Filtration (1,2)	-Calcination/ Cement Kiln (1,2) -Rotary Kiln (1,2,3)	-	-Secure Landfill (2,3)
PCB Wastes	242	Liquid, solid sludge	- Oil (after dehalogenation)	-	- Carbon Adsorption (1) - Resin Adsorption (1) - Dehalogenation (1,2) - Centrifugation (1,2) - Filtration (1,2)	-Rotary Kiln (1,2,3) -Calcination/ Cement Kiln (1,2) -At Sea Incineration (1,2,3)		-Above Ground Storage (1,2,3)

* In categories where the waste streams are in more than one physical form - i.e., liquid, sludge, solids - the following code is used to indicate appropriate treatment/disposal:

TREATMENT/DISPOSAL CODE:

1. SUITABLE FOR LIQUIDS
2. SUITABLE FOR SLUDGES
3. SUITABLE FOR SOLIDS

- A wastewater treatment plant is a necessary component in a waste management system to treat liquid wastes, effluents from some physical/chemical treatment processes (i.e., centrifugation, dewatering) and quench and scrubbing waters from incineration.

- Oily wastes and a variety of solvent wastes have the greatest potential for recovery and reuse. Recovery and reuse of these wastes may be accomplished by a number of physical /chemical processes.

- A wide range of biological treatment methods is available. Currently the activated sludge process and landfarming are the most widely used biological treatment methods in Ontario. Novel biological treatment technologies such as the powdered activated carbon-powdered activated sludge processes may have some future application in a waste management system. Generally, wastes amenable to biological treatment can also be treated by other means, e.g., physical/chemical or thermal processing. However, biological treatment is usually the less expensive process.

- Physical/Chemical treatment technologies are fundamental to a waste management system. The effectiveness of these processes has been demonstrated in industrial applications for a broad range of waste streams generated by a multitude of industries. Physical/Chemical facilities can be designed to accommodate any volume of waste, but economics generally favour a large size treatment facility.

- The rotary kiln incinerator has potential to burn most solid and liquid wastes which cannot be effectively treated or disposed of by other technologies. It has proven demonstrability and is the 'workhorse' in most waste management systems.

- Solidification/stabilization of inorganic wastes and wastes having a limited organic content is a currently viable technology. In the 'implementation framework' the utilization of a solidification process dictates a dependence on secure landfill for the ultimate disposal of the stabilized wastes.

- Secure landfill is necessary for the ultimate disposal of those waste residuals and treated sludges that are still potentially hazardous. All current waste management systems reviewed incorporated landfill as part of the system.

2.3 IMPLEMENTATION FRAMEWORK

A potential implementation framework for the treatment and disposal of liquid industrial waste and hazardous waste must consider:

- Sources, characteristics and quantities of wastes generated.
- Existing recycle/reuse/reclamation, treatment and disposal.
- Government waste management regulations.
- Facility location.
- Economics of haul.
- Applicable technologies for the management of incoming wastes.
- Capital and operating cost of applicable technologies.
- Permissible levels of contaminants released into the environment.

Figures 2-1 to 2-5 present generic implementation frameworks for major waste streams generated in Ontario. The considerations noted above are not taken into account in these figures. Rather, they are intended to describe the inter-relationship of technologies and identify potential strategies on a preliminary basis for waste management in Ontario. It is not intended to describe or depict all potential treatment methods or potential recovery approaches in these scenarios. Further study of the implementation framework considerations (i.e., Systems Study) are required to develop these preliminary waste stream-technology matches.

Figure 2-1 presents an implementation framework for metal finishing and inorganic chemical wastes which correspond to the Waste Stream Description Categories: Heavy Metal Solutions and Residuals; Miscellaneous Chemicals and Products; Aged and Chemical Intermediates; Anion Complexes; Sludges and Residuals; and Clean Up Residues. Treatment processes deemed potentially applicable include:

- At-source recovery of metals and acids.

- Physical/chemical treatment such as oxidation, reduction, neutralization, cyanide destruction and waste concentration.

- Solidification/stabilization or geologic isolation.

- A wastewater treatment facility for effluents.

Figure 2-2 represents an implementation framework for some organic residues and sludges. The applicable Waste Stream Description Categories are: Organic Sludges and Still Bottoms; Solvents and Organic Solution (Residues after recovery step); Miscellaneous Chemicals and Products; Aged and Chemical Intermediates; Paint and Organic Residuals; Aqueous Solutions with Organics; Pesticides, Herbicides and Wastes; PCB Wastes; and Clean Up Residues.

At-source recovery or pre-treatment of the organic residues and sludges utilizing biological and physical/chemical processes such as concentration or dewatering could precede treatment or disposal at an off-site facility.

Off-site technologies to cope with sludges in this scenario could include:

- Thermal processing (incineration)
- Secure landfill site
- Solidification/stabilization prior to secure landfill

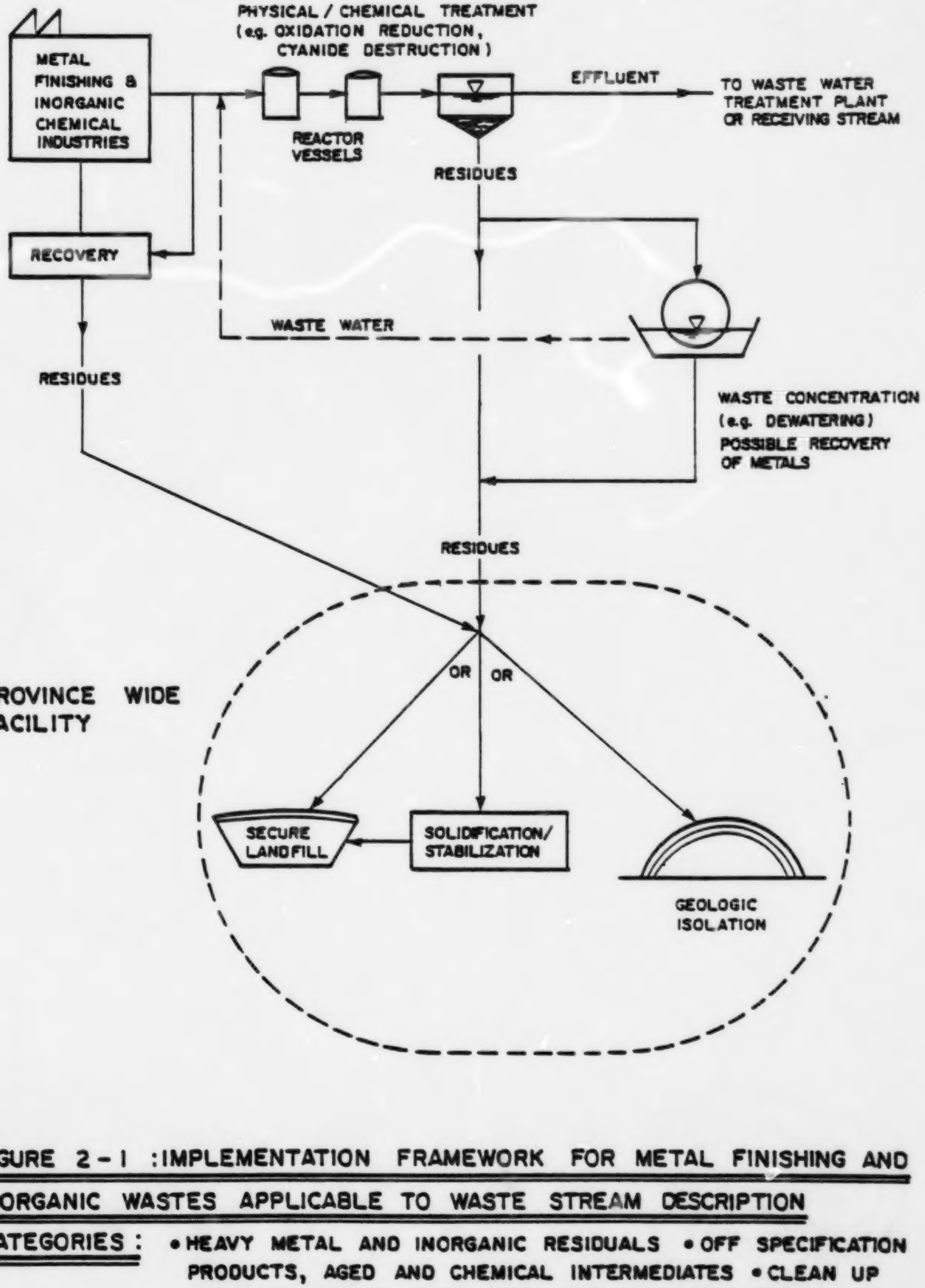
PHYSICAL / CHEMICAL TREATMENT
(e.g. OXIDATION REDUCTION, CYANIDE DESTRUCTION)
METAL FINISHING & INORGANIC CHEMICAL INDUSTRIES
REACTOR VESSELS
EFFLUENT
TO WASTE WATER TREATMENT PLANT OR RECEIVING STREAM
RESIDUES
RECOVERY
WASTE WATER
RESIDUES
WASTE CONCENTRATION
(e.g. DEWATERING)
POSSIBLE RECOVERY OF METALS
RESIDUES
OR
OR
PROVINCE WIDE FACILITY
SECURE LANDFILL
SOLIDIFICATION/ STABILIZATION
GEOLOGIC ISOLATION

FIGURE 2 - 1 :IMPLEMENTATION FRAMEWORK FOR METAL FINISHING AND INORGANIC WASTES APPLICABLE TO WASTE STREAM DESCRIPTION CATEGORIES : • HEAVY METAL AND INORGANIC RESIDUALS • OFF SPECIFICATION PRODUCTS, AGED AND CHEMICAL INTERMEDIATES • CLEAN UP RESIDUES • ANION COMPLEXES • DRY AND INERT RESIDUALS.

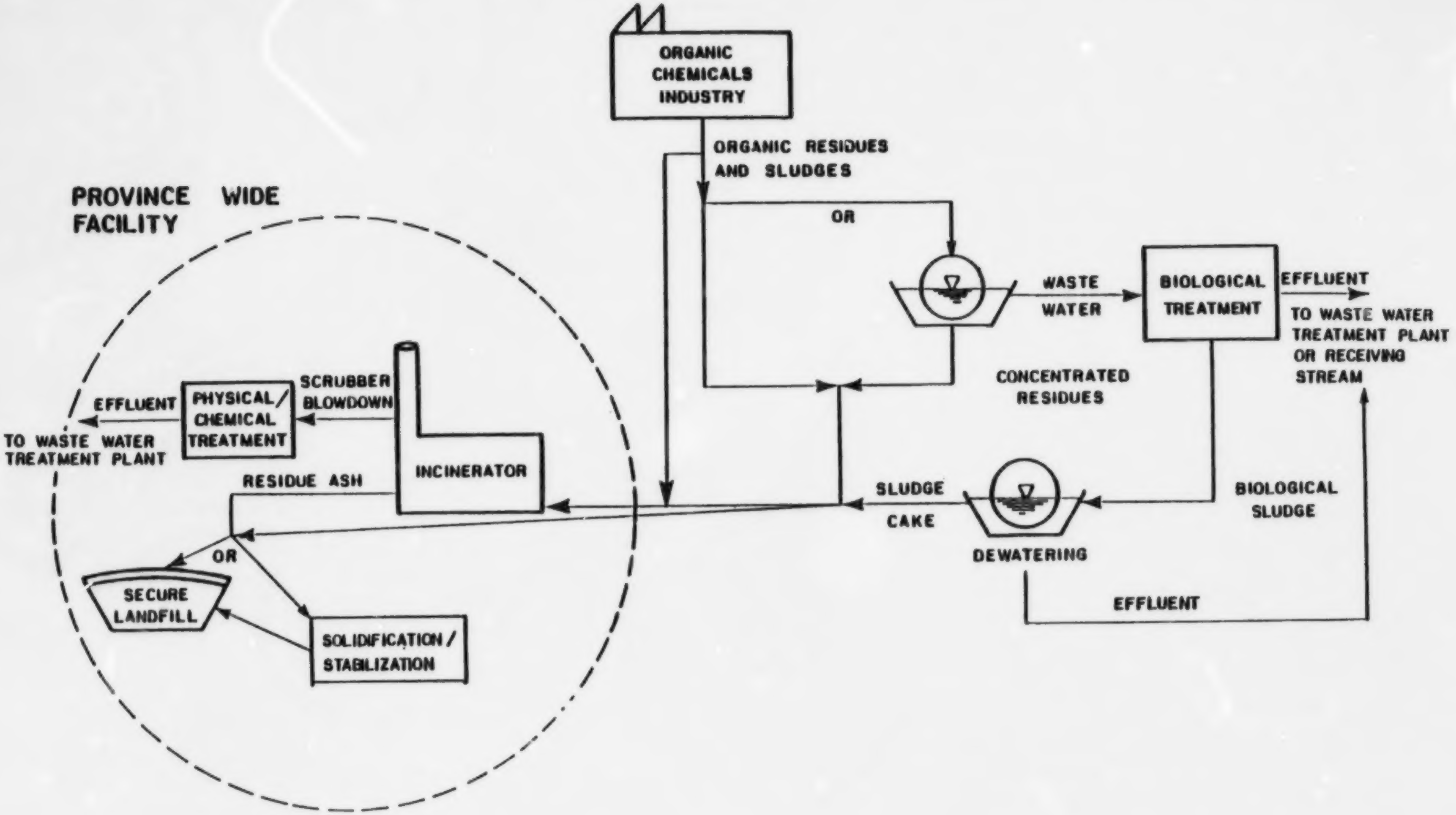
ORGANIC CHEMICALS INDUSTRY
ORGANIC RESIDUES AND SLUDGES
OR
WASTE WATER
BIOLOGICAL TREATMENT
EFFLUENT
TO WASTE WATER TREATMENT PLANT OR RECEIVING STREAM
CONCENTRATED RESIDUES
BIOLOGICAL SLUDGE
SLUDGE CAKE
DEWATERING
EFFLUENT
PROVINCE WIDE FACILITY
SCRUBBER BLOWDOWN
PHYSICAL/ CHEMICAL TREATMENT
EFFLUENT
TO WASTE WATER TREATMENT PLANT
INCINERATOR
RESIDUE ASH
OR
SECURE LANDFILL
SOLIDIFICATION / STABILIZATION

FIGURE 2-2 : IMPLEMENTATION FRAMEWORK FOR ORGANIC RESIDUES AND SLUDGES

APPLICABLE TO WASTE STREAM DESCRIPTION CATEGORIES: • ORGANIC SLUDGES AND STILL BOTTOMS, • SOLVENT AND ORGANIC SOLUTIONS (RESIDUES AFTER RECOVERY) • OFF SPECIFICATION PRODUCTS, AGED AND CHEMICAL INTERMEDIATES • PAINT AND ORGANIC RESIDUALS • PESTICIDES, HERBICIDES AND WASTES • AQUEOUS SOLUTIONS WITH ORGANICS • CLEAN UP RESIDUES • PCB WASTES

Figure 2-3 presents an implementation framework for wastes generated from petroleum refining industries which corresponds to Waste Stream Description Categories: Oils and Grease; Oil/Water Mixtures; and Organic and Oily Residuals which are typically generated from refining operations. Many petroleum industry wastes undergo at-plant treatment prior to off-site disposal. In-plant processes may include recovery, oily sludge land treatment, biological treatment and concentration/dewatering. The majority of the wastes reaching an off-site facility would be oily sludges and biological treatment sludge filter cakes. Thermal processing and secure landfilling would be required to treat and dispose of the wastes requiring off-site treatment.

Figure 2-4 outlines an implementation framework for the following Waste Stream Description Category: Heavy Metal Solutions and Residuals. Wastes such as spent pickle liquors are generated chiefly by the steel industry and metal finishing plants.

On-site physical/chemical processes described in Figure 2-4 could include:

- Acid recovery
- Precipitation of heavy metals
- Settling and dewatering/concentration to give a low-volume heavy metal sludge.

Metal-laden sludge will usually require off-site disposal at a secure landfill site or stabilization/solidification prior to landfilling.

Figure 2-5 identifies an implementation framework for saline wastes which corresponds to Waste Stream Description Category: Miscellaneous Chemicals and Products, Aged and Chemical Intermediates. These waste streams do not usually receive at-source pretreatment and recovery is not presently feasible.

Available off-site technologies appropriate for the disposal of these wastes include:

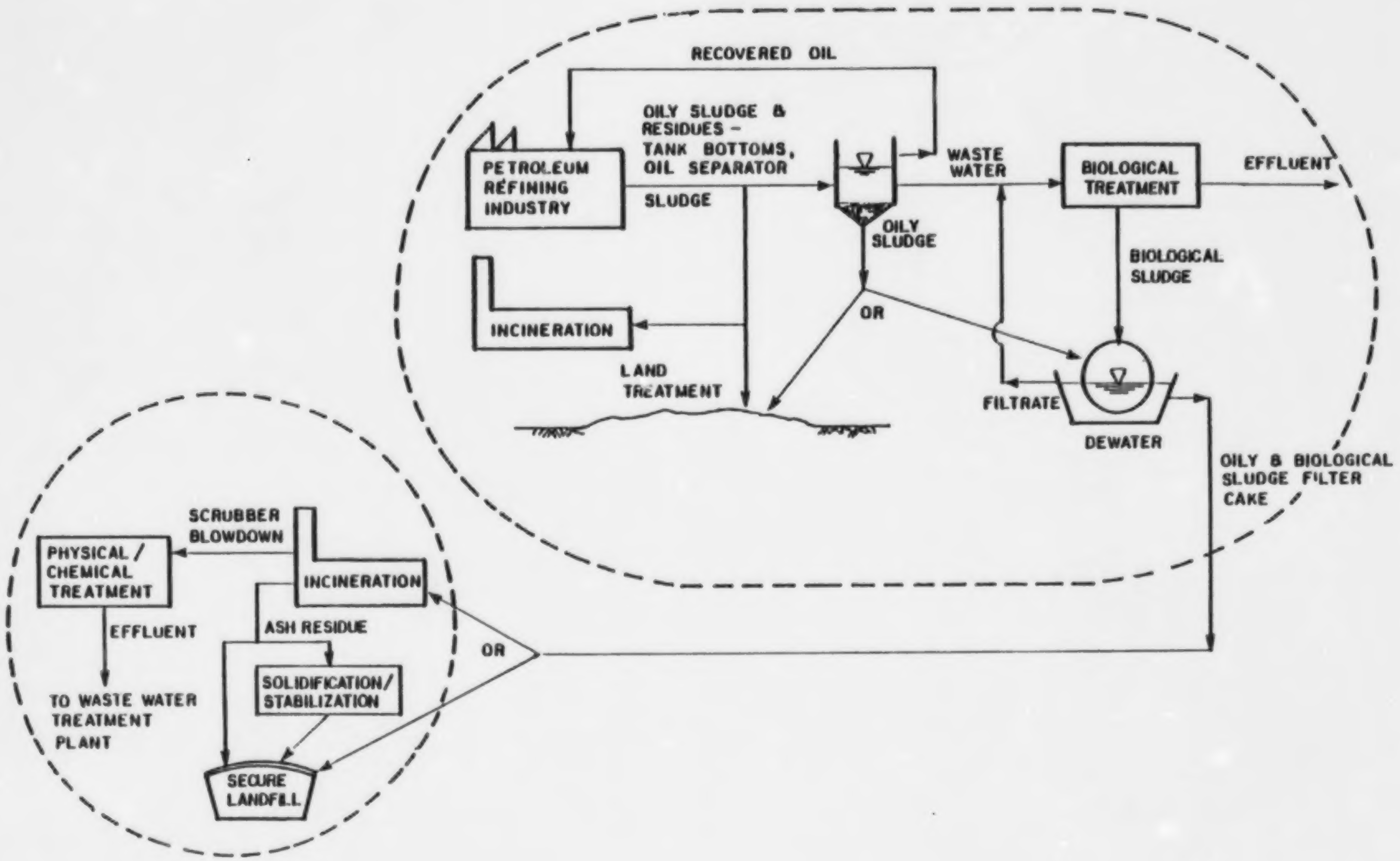
RECOVERED OIL
PETROLEUM REFINING INDUSTRY
OILY SLUDGE & RESIDUES - TANK BOTTOMS, OIL SEPARATOR SLUDGE
WASTE WATER
BIOLOGICAL TREATMENT
EFFLUENT
OILY SLUDGE
BIOLOGICAL SLUDGE
OR
INCINERATION
LAND TREATMENT
FILTRATE
DEWATER
OILY & BIOLOGICAL SLUDGE FILTER CAKE
SCRUBBER BLOWDOWN
PHYSICAL / CHEMICAL TREATMENT
INCINERATION
ASH RESIDUE
OR
EFFLUENT
SOLIDIFICATION/ STABILIZATION
TO WASTE WATER TREATMENT PLANT
SECURE LANDFILL

FIGURE 2-3 : IMPLEMENTATION FRAMEWORK FOR OILY RESIDUES AND SLUDGE APPLICABLE TO WASTE STREAM DESCRIPTION CATEGORIES: • OILS AND GREASE, • OIL / WATER MIXTURES • ORGANIC AND OILY RESIDUALS

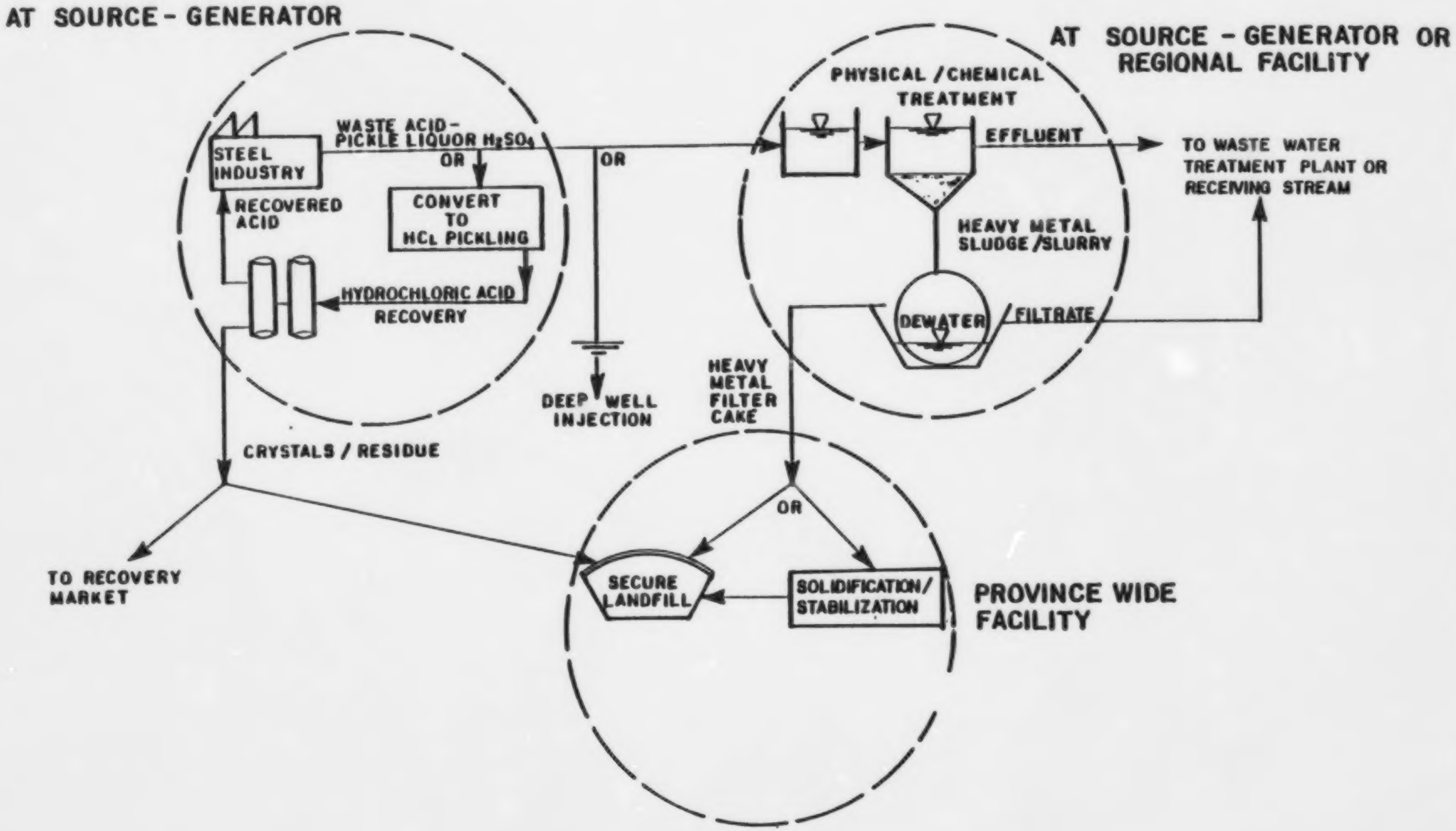
AT SOURCE - GENERATOR
STEEL INDUSTRY
WASTE ACID-PICKLE LIQUOR H_2SO_4
OR
CONVERT TO HCL PICKLING
RECOVERED ACID
HYDROCHLORIC ACID RECOVERY
CRYSTALS / RESIDUE
TO RECOVERY MARKET
OR
DEEP WELL INJECTION
AT SOURCE - GENERATOR OR REGIONAL FACILITY
PHYSICAL / CHEMICAL TREATMENT
EFFLUENT
TO WASTE WATER TREATMENT PLANT OR RECEIVING STREAM
HEAVY METAL SLUDGE / SLURRY
DEWATER
FILTRATE
HEAVY METAL FILTER CAKE
OR
SECURE LANDFILL
SOLIDIFICATION/ STABILIZATION
PROVINCE WIDE FACILITY

FIGURE 2-4 : IMPLEMENTATION FRAMEWORK FOR WASTE ACIDS APPLICABLE TO WASTE STREAM DESCRIPTION CATEGORY: HEAVY METAL & INORGANIC RESIDUALS

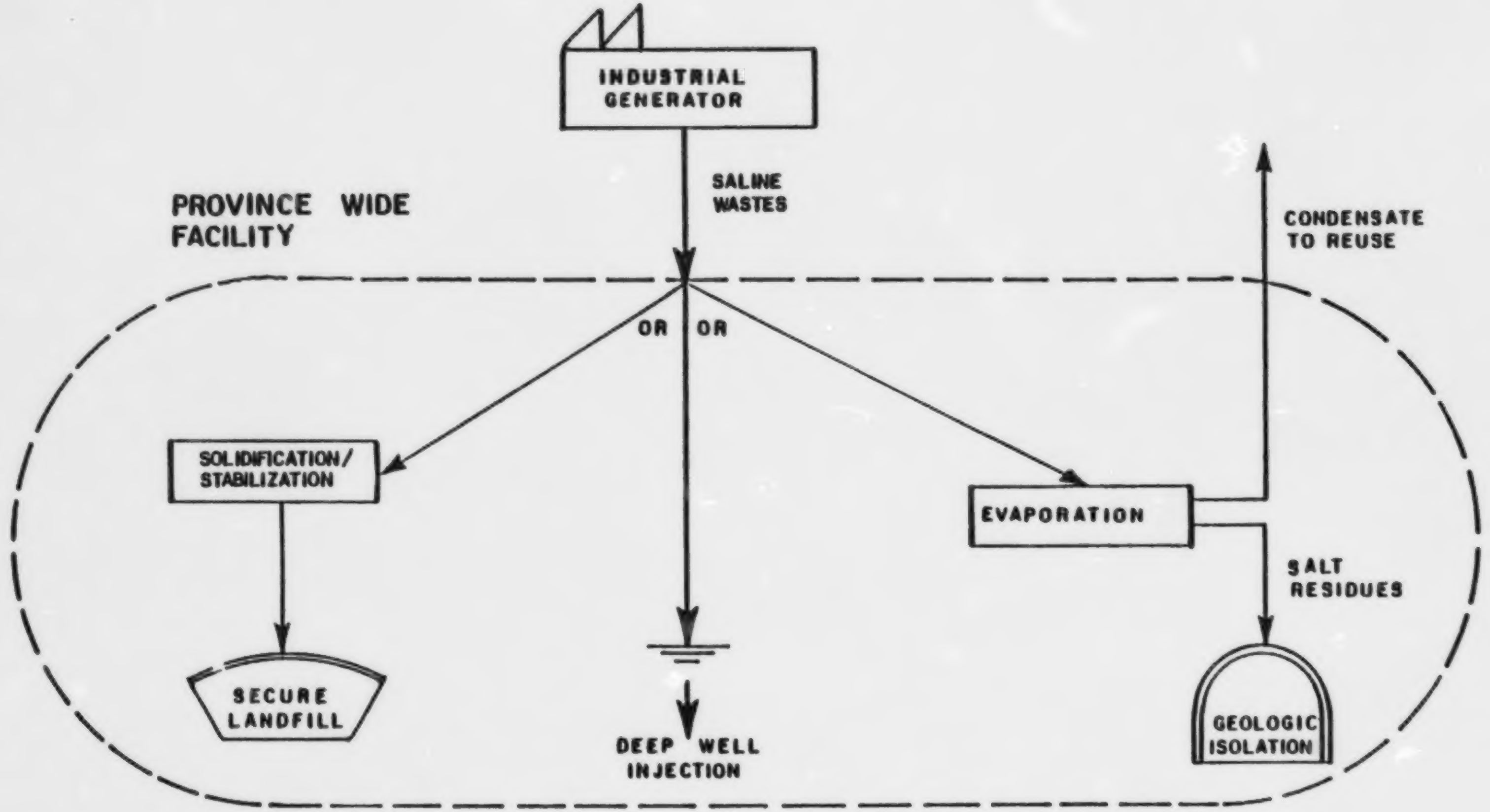
INDUSTRIAL GENERATOR
SALINE WASTES
PROVINCE WIDE FACILITY
OR
OR
SOLIDIFICATION/ STABILIZATION
SECURE LANDFILL
DEEP WELL INJECTION
EVAPORATION
CONDENSATE TO REUSE
SALT RESIDUES
GEOLOGIC ISOLATION

FIGURE 2-5 :IMPLEMENTATION FRAMEWORK FOR SALINE WASTES ALSO APPLICABLE TO

WASTE STREAM DESCRIPTION CATEGORY: • OFF SPECIFICATION PRODUCTS, AGED AND CHEMICAL INTERMEDIATES

- Deep well injection
- Secure landfill
- Geologic isolation.

Figure 2-6 is an overall generic implementation framework identifying three levels of waste management.

- At-source abatement, reduction, recovery, recycle and treatment.
- Off-site treatment and disposal at a regional level (i.e., serving several industries within a limited geographical area)
- Off-site facilities serving industry on a province-wide basis.

As the cost of raw materials, transportation and off-site disposal increase, industries will strive to reduce the volume of wastes generated. Techniques currently employed by generators to lessen the amount of wastes produced or to decrease the volume requiring off-site disposal include process alterations, recovery and reuse of solvents and oils, physical/chemical treatment (e.g., dewatering, neutralization); and biological treatment (e.g., land farming). Implementation of on-site reduction/treatment technologies will decrease the quantity and change the characteristics of the wastes requiring off-site disposal.

An implementation framework has been presented for off-site regional facilities which would treat and dispose of similar wastes within a regional catchment area. These facilities would include transfer stations which could serve as collection and bulking stations or incorporate physical/chemical treatement technologies such as concentration/dewatering and neutralization.

Off-site OWMC facilities could include facilities for treatment and ultimate disposal technologies which are specialized and are normally not cost-effective at on-site or off-site regional facilities.

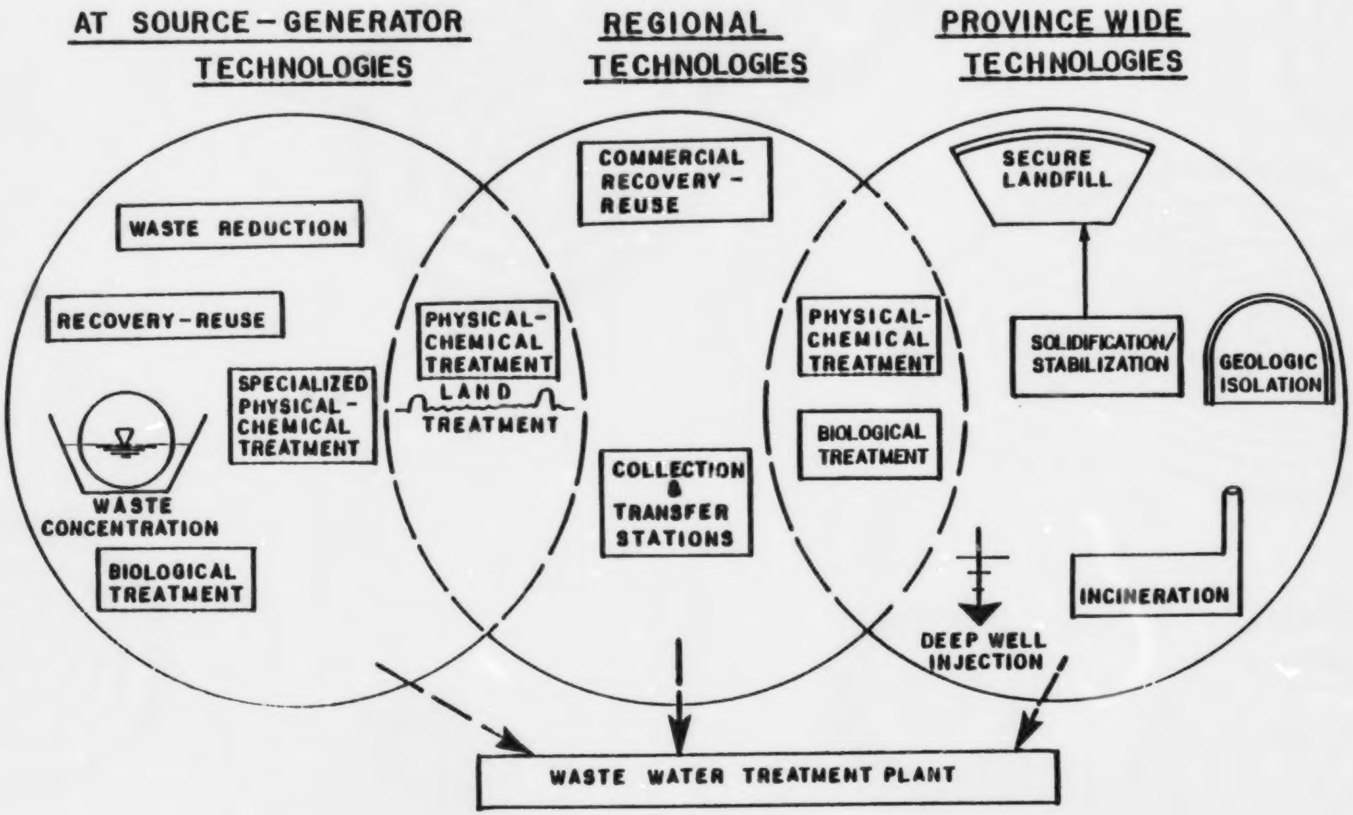
AT SOURCE – GENERATOR TECHNOLOGIES
REGIONAL TECHNOLOGIES
PROVINCE WIDE TECHNOLOGIES
WASTE REDUCTION
RECOVERY – REUSE
SPECIALIZED PHYSICAL – CHEMICAL TREATMENT
WASTE CONCENTRATION
BIOLOGICAL TREATMENT
PHYSICAL- CHEMICAL TREATMENT
LAND TREATMENT
COMMERCIAL RECOVERY – REUSE
COLLECTION & TRANSFER STATIONS
PHYSICAL- CHEMICAL TREATMENT
BIOLOGICAL TREATMENT
SECURE LANDFILL
SOLIDIFICATION/ STABILIZATION
GEOLOGIC ISOLATION
DEEP WELL INJECTION
INCINERATION
WASTE WATER TREATMENT PLANT

FIGURE 2 – 6 : IMPLEMENTATION FRAMEWORK TO LIQUID INDUSTRIAL WASTE AND HAZARDOUS WASTE MANAGEMENT IN ONTARIO

The implementation framework suggested in Figure 2-6 identifies technologies such as:

- Physical/chemical treatment
- Thermal processing (incineration)
- Secure landfill
- Geologic isolation
- Solidification/stabilization prior to secure landfill.

The 'Implementation Frameworks' depicted in this report outline preliminary management scenarios from generator to ultimate treatment and disposal. At this stage, these scenarios are conceptual and consider only the matching of generic technologies to waste streams.

3.0 WASTE MANAGEMENT TECHNOLOGIES - GENERAL DESCRIPTIONS

3.1 WASTE ABATEMENT, REDUCTION, REUSE AND RECYCLE

Introduction

This topic is to be the subject of a separate in-depth study for the Ontario Waste Management Corporation, and is, therefore, only briefly covered in this report. The specificity of processes to both waste streams and to the potential industrial users of reduced, reusable or recyclable streams, makes it very difficult to discuss generic processes in the format being followed in the other chapters in this report. Many reduction and recycle systems utilize the technologies or combinations of the technologies described in those chapters, particularly those from the Physical/Chemical treatment section, e.g. electrodialysis, reverse osmosis, ultrafiltration, and precipitation.

While the subject is difficult to cover in the format used in most of this report, it is a topic which is extremely important because of its impact on the nature of waste streams which will require treatment. A general discussion format is used in this chapter, highlighted with specific illustrative examples to emphasize certain points.

Background

The aim of many environmentally conscious proponents of waste abatement, reduction, reuse and recycle processes, is to eliminate the need for waste treatment and disposal facilities. In a free market society, recovery practices will not be implemented unless the economics of recovery and reuse of a waste are more favourable than the economics of environmentally safe disposal of the waste, and purchase of replacement virgin raw materials. The likelihood is, in the foreseeable future, that there will remain a need for the safe treatment and disposal of residual industrial wastes. There is, however, an acceleration towards technologies that produce little or no waste and the recovery of resources from some wastes streams. This move is being fuelled by three major economic driving forces:

- The increasing cost of certain raw materials
- The rapidly increasing cost of energy to process those materials, and
- The increasing cost of environmentally safe treatment and disposal of wastes.

All three factors are causing waste generators to seriously consider the recovery of values from their waste, or the elimination of the waste. The increasing cost of acceptable treatment and disposal is encouraging generators who cannot eliminate their waste or recover anything of value, to at least reduce the volume of their waste.

The effect of these activities on waste treatment and disposal facilities must be considered. While the absolute volumes of waste are being reduced, the residual byproduct of the waste reduction and resource recovery activity may be much more difficult to handle. Taking solvent recovery as an example, these operations generally end up with a residual material which is very high in ash in many cases, and may be barely pumpable at ambient temperatures. This waste stream is much more difficult to handle at the waste treatment plant than the original contaminated solvent waste. Many waste treatment facilities rely on receiving a certain amount of contaminated solvent and oily wastes to fire their waste incinerators which are used to burn wastes like the high ash from solvent distillation and other solid and pasty materials. The recovery of these wastes and hence their removal from the waste stream is forcing incinerator operators to buy fuel to run their waste incinerators.

Drum reclaiming operations are another example of reclamation which creates other wastes for treatment and disposal. The cleaning of used chemical drums for subsequent reuse creates a very complex aqueous waste stream, containing alkali paint sludges plus the remnants of whatever was originally in the drum. This waste stream is not only complex; its composition varies from day to day depending upon the drums being processed.

The two preceding paragraphs above were not written to condemn the activities described but to point out that there are aspects of waste reduction which impinge on the selection of waste treatment and disposal technologies owing to the residuals of the recovery processes.

Waste Abatement

The definition of waste abatement is as follows:

> "Substitution of a new low-waste or non-waste primary industrial process for an old process to eliminate or drastically reduce the quantity of waste produced".

This is obviously very individual industry-specific. To try to illustrate what is meant, three examples are given:

- **Surface Finishing Industry** Many electroplaters use the cyanide salts of the various metals which they are plating out onto their products. Cyanide waste is a major problem for the electroplating industry, since it is highly toxic and very expensive to treat. Several electroplaters have substituted alternative salts of the plating metals and have thus eliminated their cyanide disposal problem. This substitution has not been without its problems and, many platers prefer to stay with the cyanide salts owing to its superior plating properties.

  Iron and Steel Industry For many years the iron and steel industry has used sulphuric acid to "pickle" (or clean) the surface of their steel prior to such operations as galvanizing etc. This gave rise to a waste stream containing iron sulphate and residual sulphuric acid which was generally referred to as spent pickle liquor. The substitution of hydrochloric acid as the pickling acid, allows the acid to be recycled. Pre-concentration of the spent acid is followed by heating of the concentrated $FeCl_2$ solution. The heat breaks down the $FeCl_2$ to Fe_2O_3 and HCl gas, which is absorbed to form hydrochloric acid and returned to the pickling tanks. Although this is also an example of a recovery process, the key to its success is really in the substitution of HCl for H_2SO_4 in the primary process. A similar decomposition of $FeSO_4$ is not possible.

- **Paint Application** Sludge from the industrial application of paints and coatings is very difficult to handle. Industrial paints and coatings are often solvent based oil and acrylic paints, which are applied to objects in a spraybooth, with a sheet of water running down behind the object being painted which washes down the paint overspray to a sump. The sump is emptied periodically. Paint sludges can be up to 90% water but have the consistency of solidified putty.

  In a new development in the paint industry, pigment and polymer are applied as a dry powder using electrostatic charging of the target object to be painted, and charging the paint spray with the opposite charge. A very high proportion of the paint impacts the object to be coated. Since it is dry, any overspray is swept up and returned to the spray gun. The coated product is then baked in a curing oven. This development totally eliminates the production of troublesome paint sludges, and it enjoys nearly 100% utilization of pigment and polymer as part of the painted product.

Waste Reduction or Modification

Waste Reduction may be defined as:

> "The reduction of the quantity of waste through good housekeeping practices or by the application of concentration technologies. Also the reduction of the hazard of wastes through simple in-plant treatment".

This is an industry-specific activity which is very much related to the operation of the individual plants within an industry. Some brief examples of waste reduction practices are given:

- **Good Housekeeping** Many non-recoverable, troublesome waste streams are the result of several waste streams being mixed in one tank. A hypothetical example might be a company using both a chlorinated and non-chlorinated solvent in their plant. By maintaining two waste solvent receiving tanks they have two readily recoverable waste streams. Mixing the two solvent wastes renders the recovery much more difficult and probably makes it uneconomical.

Zinc galvanizing is an industry which has zinc-rich waste streams and non-zinc acid wastes. Mixing these wastes gives a rather large volume non-recoverable acid waste. If the wastes are segregated, the large volume of virtually zinc-free pickle acids can be sent for recovery of iron salts, leaving a smaller volume zinc-rich waste stream for disposal.

- **Metals Recovery From Electroplating Rinse Waters** In the past, electroplaters have treated their dilute rinse waters containing low concentrations of heavy metals, e.g, zinc, cadmium, chromium, etc., with lime to precipitate an alkaline sludge containing the heavy metals. This sludge is quite voluminous and expensive to dispose. Many electroplaters are now installing rinse water treatment processes, such as electrodialysis and reverse osmosis (see Physical/Chemical Treatment processes chapter), to concentrate the metal salts which are returned to the plating baths, while the purified water is either discharged or reused in the rinse tanks. Thus, sludge and the costs of sludge disposal are eliminated. Savings are also realized on the costs of raw material for the plating process.

- **Waste Volume Reduction** Because of the high cost of transportation, and the fact that waste treatment and disposal costs are related to volumes handled, many industries are undertaking some form of pretreatment of wastes for volume reduction prior to shipment. Examples might include the simple mixing of acid and alkali wastes to neutralize and precipitate a sludge which is filtered and shipped as the waste product rather than the individual waste acid and alkali streams. Care must be taken to ensure that the water from this dewatering process is suitable for discharge to a sewerage system.

Many of the technologies discussed in the chapter on Physical/Chemical Treatment technologies may be applied by industry to concentrate their waste prior to shipment. Ultrafiltration/reverse osmosis, carbon adsorption, resin adsorption, electrodialysis, filtration, etc. are all low energy concentration technologies which could be applied to this task.

Waste Reuse

This option may be defined as follows:

> "The direct reuse of a waste, as a raw material, as-is, or with very minor modification."

This is also a very plant specific operation, and many times the internal reuse of by-products has been practiced for so long that it is not thought of as waste reuse, but as part of the manufacturing process. As an example, at an integrated steel complex, coke for use in the blast furnace is produced from coal by a gasification process. The by-product gas is used as a fuel in other areas of the steel mill. In most thermoplastic fabricators operations, any trim (known as "home scrap") is returned to be remelted and reprocessed. Many of the giants of the German chemical industry today, for example, Bayer, BASF and Hoechst began operating as waste reusers. The growing practice of coal or manufactured gas production in the 19th century resulted in the simultaneous co-production of tar, ammonia, benzole, phenolics, etc. The innovative use of this waste as a raw material for dyestuffs, pharmaceuticals and other chemical production resulted in the establishment of these three large corporations.

The re-use of waste in plants or industries other than the producing plant, requires a little more effort than the internal re-use of the waste. There are legal and quality assurances which must be harmonized between the generator and potential user. Perhaps the most common barrier to widespread external reuse of waste is that potential users do not know the generator that has this waste. This problem is being addressed by various organizations known as Waste Exchanges.

In Canada the Canadian Waste Materials Exchange publishes a bulletin six times per year in which generators list waste which are available, while potential users can list waste which they are seeking as substitute raw materials. The bulletin is sent to several thousand industrial participants; any potential users or potential suppliers of the listed wastes are contacted with the listors, and the parties involved negotiate a satisfactory arrangement. The Canadian Exchange is involved only in the dissemination of information, acting more or less as a "marriage broker". Other Waste Exchanges may actually participate in the negotiations and may take possession of the waste prior to reselling to a user.

Examples of reuse by others of waste are:

- Solvents used in the electronics industry for contact cleaning or circuit board cleaning are only very slightly contaminated before they are deemed unsuitable for further use. These solvents can be readily used directly by the paint industry with no intermediate purification steps.

- By-product phenol from petroleum refining operations at about 96 -98% purity can be reused in the production of phenolic thermoset plastic resins.

- Fly ash from electrical power generation is used as a raw material in the production of lightweight aggregate and lightweight structural concrete.

Waste Recycle and Recovery

This may be defined as:

> "The reclamation of value from waste streams through the application of reprocessing technologies, consisting of unit processes such as distillation, etc."

The previous three sections have discussed activities which are very industry specific, and are accomplished in-house by industry. Waste Recycle and Recovery may be also practiced within an industry, or it may form the basis of a separate secondary industry, or it may indeed be part of the activity of a central treatment and disposal facility. Recycle and Recovery is still very waste-specific, but three technologies which are broader in the range of industry wastes to which they are applicable, and which might be considered as part of a treatment facility, are discussed below.

- **Solvent Recovery** The variety of solvents which can be processed in recovery operations include: [1]

  1. Halogenated hydrocarbons such as methylene chloride and trichloroethylene used in degreasing, metal cleaning, and dry cleaning.

  2. Aliphatic and aromatic hydrocarbons, alcohols, acetone, hexane, and butyl acetate used in various chemical process industries such as paint manufacturing, printing operations and industrial paint uses.

  3. Numerous special solvents such as Freon and phenol.

  If a simple mixture of solvent and contaminant with large differences in volatilities is the waste to be treated, or if the purity of the recovered solvent does not have to be too high, a simple distillation process can be used. Waste is fed to a simple pot still where the solvent is vapourized and routed to a condensing unit, and the contaminants which remain in the "still bottom" or sludges are drawn off for subsequent disposal.

  If a complex mixture of solvents must be separated or if the purity requirements of the recovered solvent are very high, an additional step is required after evaporation of the solvent vapours. In this case a "fractionation column" is utilized. When operated in a continuous mode, this fractional distillation process will produce a high-purity single solvent product. Operated in a batch mode, fractional distillation can yield several solvent products, the most volatile solvent being produced first followed by the next most volatile, and so forth.

Figure 3.1.1 illustrates the principal equipment used and an approximate mass-balance for a solvent recovery operation.

The most common equipment used as an evaporator in the solvent recovery industry is a Wiped Film Evaporator. This type of evaporator consists of a vertical cylinder surrounded by a heating jacket. Liquid is spread on the interior of the heated cylinder wall by means of a rotating blade mechanism. The liquid is allowed to flow down the wall as a thin film to the bottom of the evaporator as vapourization of the more volatile fractions occurs. This type of equipment is suitable for the distillation of solvents from highly viscous liquids. [2]

Other equipment used includes jacket still pots or direct steam injection.

Fractionation columns are generally vertical towers which have either trays or high surface area packing to enhance the contact between liquid and vapour in the tower.

Solvent recovery is a well established and developed process. Many private recovery operations exist in Canada, particularly for the simple recovery of single solvents contaminated with grease, solids, etc. Increased use of fractionating towers is projected to handle mixed solvents and to generate products of greater value. The costs of solvent recovery have been estimated to be about 1.5¢ - 5¢ per litre of recovered solvent.

The disposal of sludge from solvent refining is the greatest potential environmental impact of solvent recovery operations. This sludge, which may be high in ash, has been used as a fuel to provide the energy requirement for the solvent recovery operations. Increasingly stringent air emission regulations are making it difficult to utilize sludge in conventional boilers.

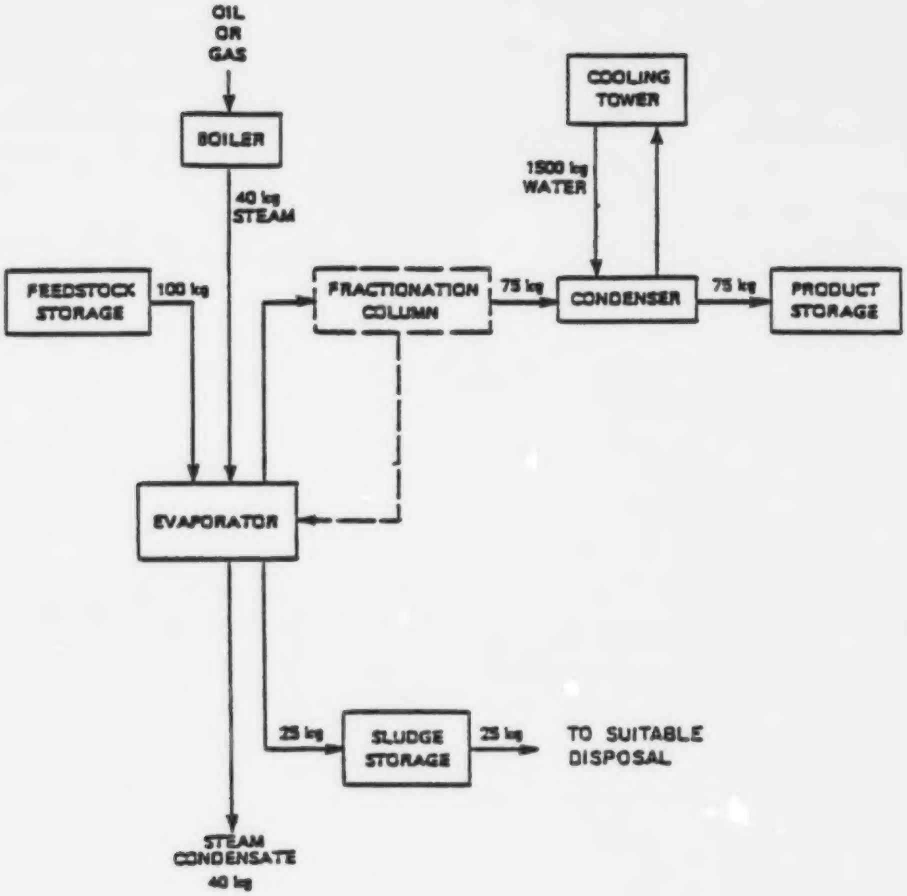
OIL
OR
GAS
BOILER
40 kg
STEAM
COOLING
TOWER
1500 kg
WATER
FEEDSTOCK
STORAGE
100 kg
FRACTIONATION
COLUMN
75 kg
CONDENSER
75 kg
PRODUCT
STORAGE
EVAPORATOR
25 kg
SLUDGE
STORAGE
25 kg
TO SUITABLE
DISPOSAL
STEAM
CONDENSATE
40 kg

FIGURE 3.1.1 :TYPICAL SOLVENT RECOVERY SYSTEM

SOURCE: SCOFIELD, 1976

- **Oil Re-Refining** The traditional process used for waste oil re-refining has been the acid-clay process as illustrated in Figure 3.1.2.[2] Feedstocks are usually used crankcase oil. In general, the conventional acid-clay process consists of the following steps:

  - Dehydration of the waste oil feedstock and removal of light ends in a steam stripping tower. (Approximately 5% of original feedstock is lost here).

  - Acidification and heating (40°C) of the dehydrated oil to extract the impurities and form a tar sludge which is allowed to settle. (Approximately 20% of original feedstock is lost here)

  - Fractionation (290 to 343°C) of the remaining waste oil into the desired streams. (Negligible losses occur here).

  - Filtration (commonly in a plate and frame filter press) of the distilled products through a clay bed to adsorb residual contaminants and colour-inducing bodies. (Usually negligible losses occur here).

There are several problems associated with the conventional acid re-refining process as applied to "modern-day" waste oils. The acidification step can cause sulphonation of the non-saturated oil fraction. Waste oils containing detergents and other additives are not readily treated by this process. Chemical requirements (primarily acid and clay) have been increasing as more and more additives are included in the newer advanced multigrade oil formulations. The acid tar and spent clay residuals are corrosive and in addition, the sludges contain significant quantities of lead and other heavy metals. The acid will tend to keep the metal content of the sludges in a potentially mobile (soluble) state thereby creating a threat to the environment. Therefore, the sludges must be disposed in an appropriate waste management system.

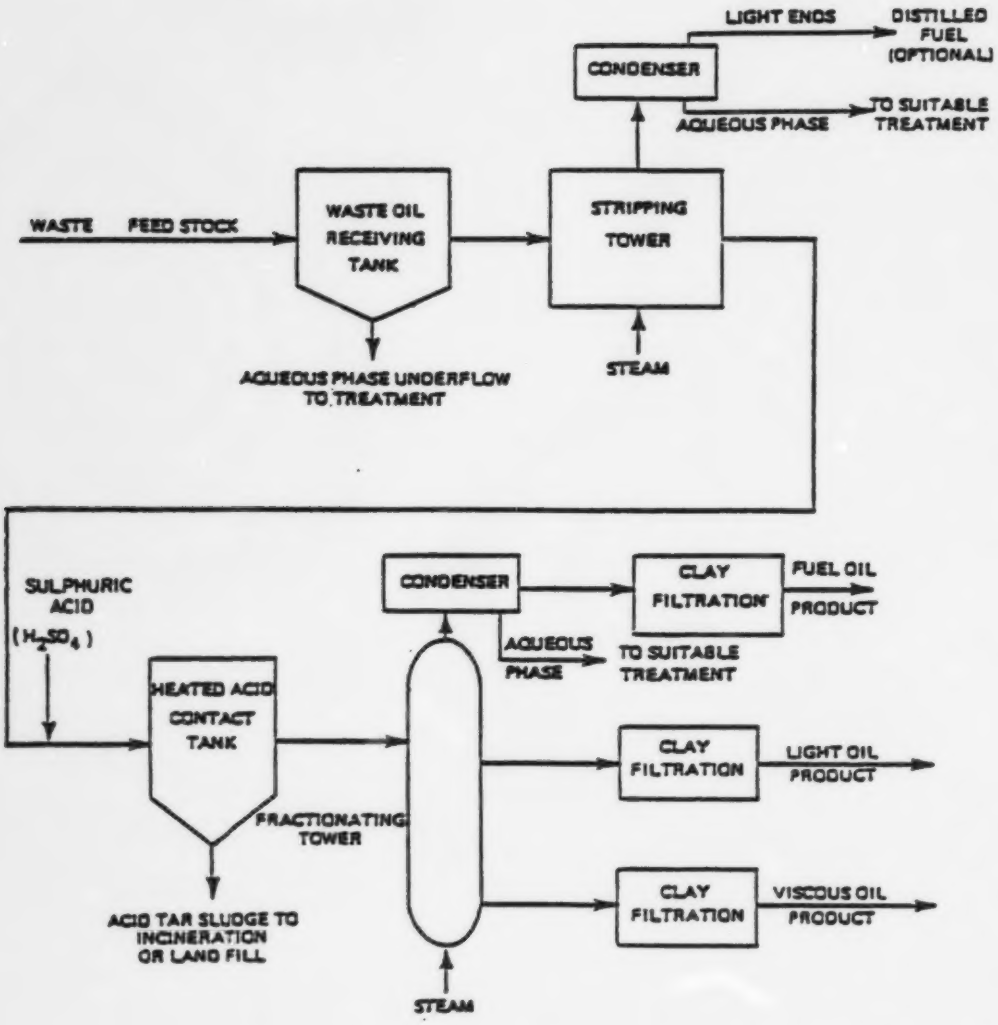
LIGHT ENDS
DISTILLED FUEL (OPTIONAL)
CONDENSER
AQUEOUS PHASE
TO SUITABLE TREATMENT
WASTE FEED STOCK
WASTE OIL RECEIVING TANK
STRIPPING TOWER
AQUEOUS PHASE UNDERFLOW TO TREATMENT
STEAM
SULPHURIC ACID
(H_2SO_4)
CONDENSER
CLAY FILTRATION
FUEL OIL PRODUCT
AQUEOUS PHASE
TO SUITABLE TREATMENT
HEATED ACID CONTACT TANK
CLAY FILTRATION
LIGHT OIL PRODUCT
FRACTIONATING TOWER
CLAY FILTRATION
VISCOUS OIL PRODUCT
ACID TAR SLUDGE TO INCINERATION OR LAND FILL
STEAM

FIGURE 3.1.2 : PROCESS SCHEMATIC FOR CONVENTIONAL ACID - CLAY WASTE OIL RE-REFINING PROCESS

SOURCE: REID CROWTHER, 1980

The acid clay process has been used for over 50 years. New processes have been developed to increase recovery and to reduce the environmental hazards posed by the by-products.

One such process is the Phillips Rerefined Oil Process dubbed PROP by its developers, the Phillips Petroleum Company. The Company claims several advantages for their process over the conventional acid-clay process, namely:

- Recoveries of 90% can be achieved.
- By-product filter cake can be safely disposed of in landfills (presumably of appropriate design).
- Following pretreatment of the aqueous phase by-products, it may be discharged to a municipal sewer system for subsequent treatment at a municipal plant.
- The metals content of the re-refined oil is less than 10 mg/L.

The PROP process consists of the following basic steps:

- Contacting of the waste oil with diammonium phosphate (DAP) to precipitate metallic phosphate compounds.
- Heating to 150°C to drive off water and various light ends.
- Filtration to remove the precipitated metallic phosphate compounds and other particulates.
- Clay filtration to remove trace inorganics and colour bodies.
- Hydrotreating over a nickel molybdate catalyst to remove sulphur, nitrogen, oxygen and chlorine compounds.

- Flashing to separate light ends.

- Stripping to remove any remaining fuel oil from the lubricating oil product.

Shell Canada has recently installed a PROP unit in Toronto and they are actively seeking waste oil feedstocks for this unit.

Approximate costs in 1980 Canadian dollars for the PROP process are:

Capacity		Average Equipment Cost (Excluding Land, Feed, Product Storage and Servicing)	Approximate Annual Operating Cost
m^3/Yr.	barrels/day		
7,600	130	$2,300,000	$ 600,000
18,900	325	3,900,000	1,200,000
37,900	650	5,400,000	2,200,000

- **Drum Reclamation** The widespread use of 45 gallon steel drums by industry to ship both products and waste materials has resulted in a number of companies specializing in the cleaning and reclamation of these containers. Figure 3.1.3 shows the basic steps involved in a typical drum reclaiming operation.

Drums in the receiving area are visually inspected for their physical condition, and any which are unsuitable for reclamation are rejected. The drums go through a pre-wash step using steam or hot water to remove any residual material adhering to the drum. From there, the drums proceed to a hot caustic wash tank which contains caustic soda at a concentration of about 10%. The bulk of the cleaning is achieved in this step. Paint and lacquers are removed from the drum by the caustic and any remaining residual material is removed. Following the caustic wash are rinse, dilute acid wash and further rinsing steps. The drums are then dried and custom painted to the purchaser's specifications.

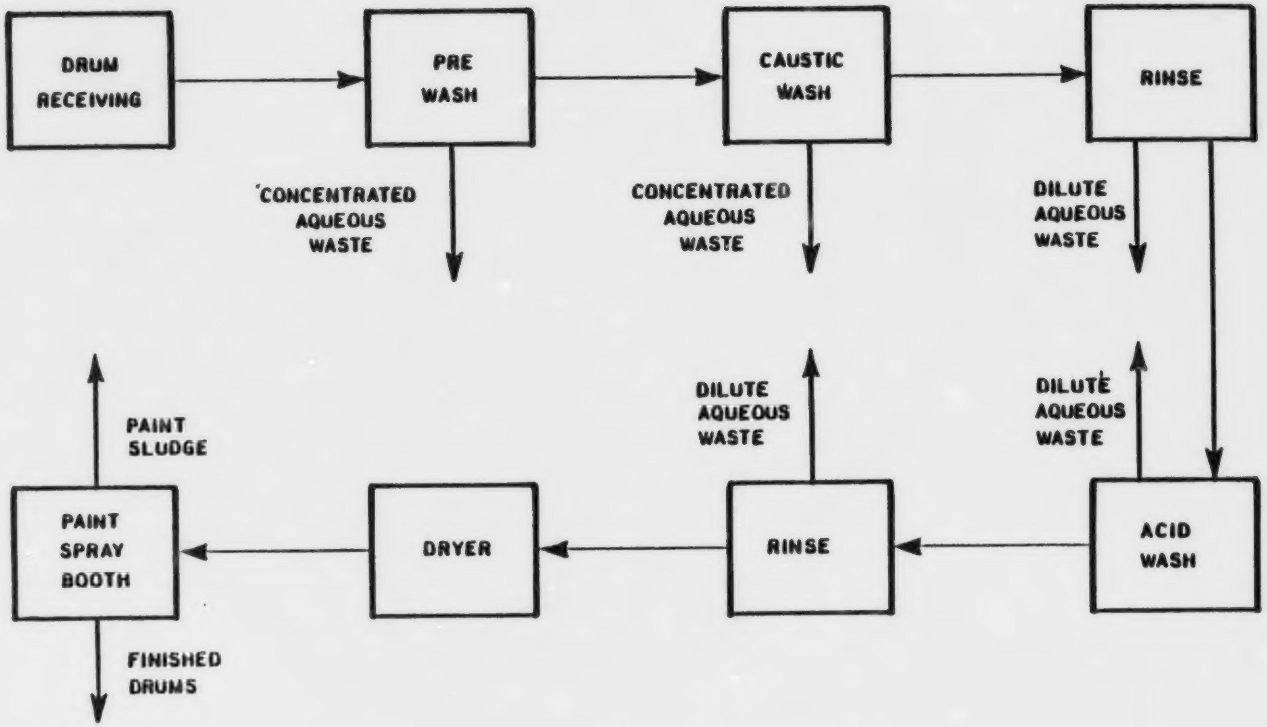
DRUM RECEIVING
PRE WASH
CAUSTIC WASH
RINSE
CONCENTRATED AQUEOUS WASTE
CONCENTRATED AQUEOUS WASTE
DILUTE AQUEOUS WASTE
DILUTE AQUEOUS WASTE
ACID WASH
DILUTE AQUEOUS WASTE
RINSE
DRYER
PAINT SPRAY BOOTH
PAINT SLUDGE
FINISHED DRUMS

FIGURE 3.1.3 : BASIC STEPS IN A TYPICAL DRUM RECLAIMING SYSTEM

> While the reclamation of steel drums is an excellent service to minimize the numbers of these rather bulky objects which must go for disposal, there is potential for a negative environmental impact if the aqueous waste from the drum washing operations are not properly disposed of. The wastes from the prewash and caustic wash steps can be very heavily contaminated. Contaminations measured as chemical oxygen demand (COD) can be as high as 900,000 mg/kg. It is also highly variable ranging from 90,000 - 900,000 mg/kg depending upon the nature of the products originally shipped in the drums. Specific contaminants contained in those wastes are also highly dependent upon the original use of the drum.

Thus, the operation of this waste recovery technology results in the production of a new waste which requires proper handling treatment and disposal.

REFERENCES

Waste Abatement, Reduction, Reuse and Recycle

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2. Reid Crowther and Partners Ltd., Hazardous Wastes in Northern and Western Canada: The Need for a Waste Management Strategy. Volume 2, Technology Review, 1980.

3.2 BIOLOGICAL TREATMENT

INTRODUCTION

Biological treatment encompasses several basic generic processes. They offer potential application to many liquid industrial and hazardous wastes generated in Ontario. The biological processes discussed in this section of the document consist of proven technologies available for application in Ontario. Indeed, the more common forms of biological treatment, e.g. activated sludge and anaerobic digestion, are employed in Ontario for the treatment of municipal as well as industrial waste waters.

Most biological processes use a mixture of micro-organisms to accomplish the treatment of wastes. The effectiveness of the micro-organisms is enhanced through favourable environmental conditions presented by the processes and through either the adaptation of the microbial population by natural selection, or the introduction of selected microbes.

The primary mechanism of biological treatment processes as they apply to wastes is the biochemical conversion of organic contaminants to less toxic (or hazardous) substances through a series of reactions. The whole range of chemical reactions are catalyzed by enzymes produced by micro-organisms. Biological treatment is essentially a form of fermentation in which organic wastes serve to supply, at least in part, the nutrient requirements of micro-organisms.

Many man-made substances are relatively difficult to degrade (refractory) since organisms have not had the opportunity to evolve so as to metabolize them. This refractory nature is often attributed to the complex structure of the chemical compounds or the presence of various chemical substitutions (e.g., chlorinated organics). Substances that cannot be changed by a single species of organism can often be degraded by mixtures of organisms. This can occur by the incidental conversion (cometabolism) by organisms which metabolize similar compounds, or the products of the initial conversion by one group of organisms may be subsequently broken down by others, until the products can be metabolized by normal pathways, ultimately to carbon dioxide and water. Example of cometabolism are known in the degradation of hydrocarbons, pesticides and herbicides.

Micro-organisms are also able to concentrate and, hence, segregate many toxic or hazardous components. Concentration is accomplished by either bioaccumulation or through biosorption.

Figure 3.2.1. illustrates the several basic mechanisms available for the treatment of wastes.

The purpose of a biological treatment system is to control and, where possible, optimize the environment for micro-organisms to conduct biological degradation of the organics in the waste. Major environmental factors include oxygen, temperature, light, pH, and nutrients (especially nitrogen, phosphorus and trace metals). The manipulation of these factors is used to influence the nature of the microbial population and to optimize biodegradation. For example, the presence of oxygen (generally added as air) ensures that aerobic microbes predominate, while its absence dictates that anaerobic microbes are present. The presence of toxic or inhibitory chemical compounds also can affect the makeup of the microbial population or, in extreme cases, prevent growth. In some cases, a series of biological reactors, each maintained under different environmental conditions, may be required to provide the wide variety of micro-organisms necessary for complete biodegradation.

A key factor in the design of biological treatment systems is to increase the ratio of microbes to waste, and hence improve the rate of waste treatment. In continuous flow systems, this is accomplished by either separating and recycling the biomass (e.g., activated sludge processes) or by permitting the micro-organisms to attach to a surface over which the liquid waste passes (e.g. trickling filters, rotating biological contactors). In batch liquid or semi-solid phase biological treatment systems, a high biomass-to-waste ratio is achieved by employing a large initial microbe population.

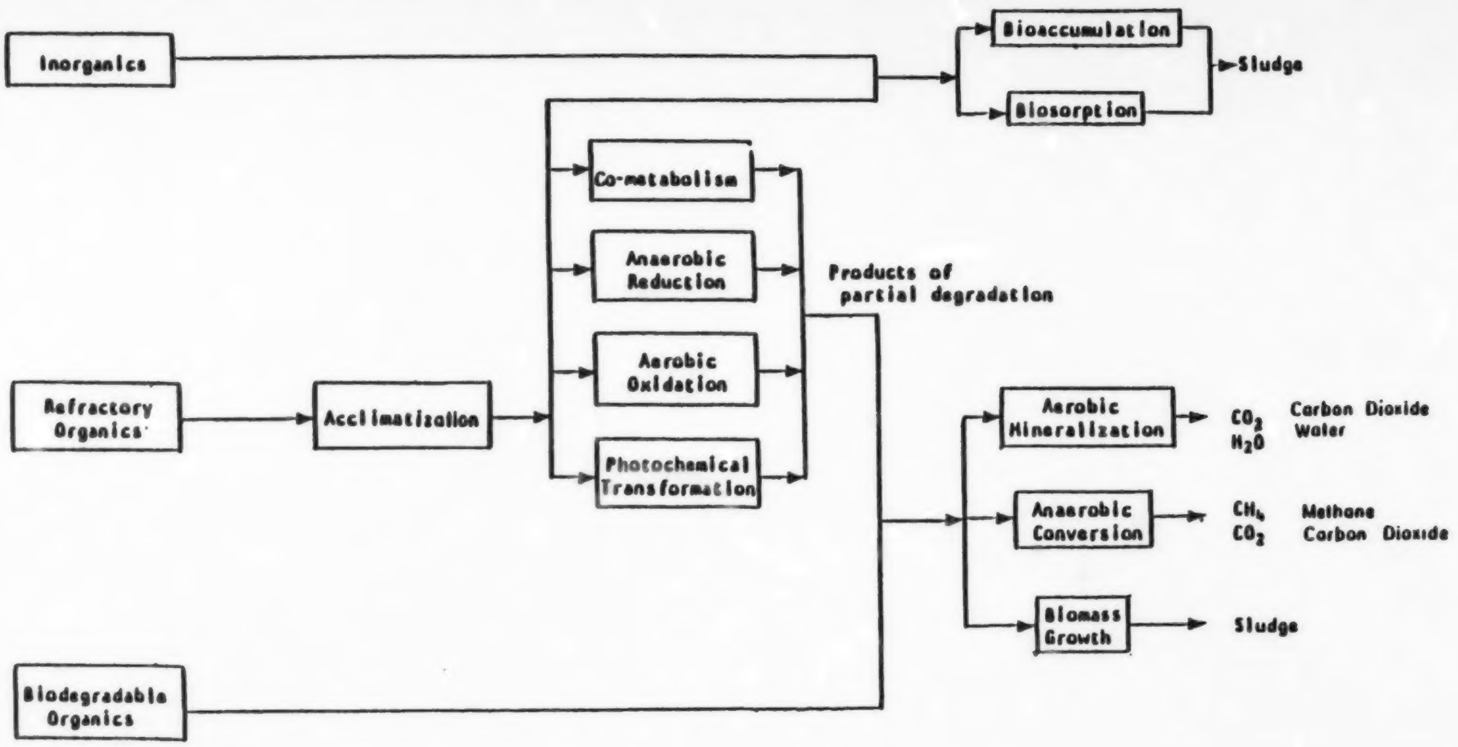

Inorganics
Refractory Organics
Biodegradable Organics
Acclimatization
Co-metabolism
Anaerobic Reduction
Aerobic Oxidation
Photochemical Transformation
Products of partial degradation
Bioaccumulation
Biosorption
Sludge
Aerobic Mineralization
Anaerobic Conversion
Biomass Growth
CO_2 Carbon Dioxide
H_2O Water
CH_4 Methane
CO_2 Carbon Dioxide
Sludge

FIGURE 3.2.1 : MECHANISM OF BIOLOGICAL TREATMENT

The most common forms of biological treatment employed are:

- **Activated Sludge:** A process in which the waste is mixed with air and biological sludge (microbial floc). The latter is separated from the clarified waste stream and recycled. There are various modifications of the basic activated sludge process such as tapered aeration, step aeration, complete mix, contact stabilization, extended aeration and pure oxygen systems.

- **Trickling Filters:** A process where wastes are allowed to trickle through a bed of rock or other packing medium. As the wastewater trickles through the bed, microbial growth occurs on the surfaces of the medium as a "fixed film" and provides the required contact between micro-organisms and organics.

- **Rotating Biological Reactors:** In this process, the waste flows through troughs in which a series of closely spaced, partially submerged discs are rotated on a horizontal shaft. A biological film attaches to the disc surface and aerobic oxidation takes place as the discs rotate. The attached growths are similar in concept to a trickling filter, except that the microbes are passed through the wastewater rather than the wastewater being passed over the microbes.

- **Fluidized Bed:** In this process the micro-organisms are attached as a film to inert particles such as sand, which are kept in suspension by the upward flow of waste and oxygen gas in a vertical column reactor (fluidized bed). The surface to volume ratio and the biological mass of the fluidized bed is very high compared to other fixed film reactors such as trickling filters and rotating biological disc reactors.

- **Waste Stabilization Ponds:** (oxidation ponds) These are large shallow ponds designed to treat wastes through the interaction of sunlight, algae, wind and oxygen. Wastewater enters at a single point and mixing is accomplished by wind currents. Algae grow by taking energy from sunlight and consuming carbon dioxide and inorganics released by the action of the bacteria in the pond. The algae in turn release oxygen to supplement the oxygen introduced into the pond by wave action. If oxygen is insufficient the ponds become aerobic-anaerobic or facultative lagoons.

- **Aerated Lagoons:** In this system, aeration equipment is installed in what is basically a waste stabilization pond to eliminate the dependence on algae produced oxygen and to reduce the area required by the ponds. Aerated lagoons are actually a form of the activated sludge process.

- **Composting:** This is also a process which is essentially the aerobic digestion of organics. Waste sludges are mixed with a bulking agent such as wood chips, shredded rubber tires or other material to provide the necessary structure and porosity for aeration and to lower the moisture content of the mass to 60% or less. This mixed material is piled or placed in windrows and aerated by turning or drawing air through the pile. The pile usually undergoes decomposition by thermophilic micro-organisms at a temperature of about 60°C or greater. After decomposition (20 - 30 days), the compost is screened and the bulking agent reused.

- **Landfarming (Land treatment):** Land farming or land treatment is essentially the composting of wastes on land. Waste liquids or sludges are mixed with surface soils and mixing and turning of the soil/waste mass together with the soil micro-organisms accomplishes aerobic decomposition of the wastes. Land treatment systems usually employ some form of irrigation where the wastewater is applied to the land by sprinkling (spray irrigation) or by surface spreading using ridge-and-furrow. An important aspect of land treatment is the adsorption of metals and organics in the wastes by soil.

- **Powdered Activated Carbon Systems:** These are essentially biophysical wastewater treatment systems. Typically, carbon is added into the aeration section of an activated sludge plant continuously or on a batch basis. There appear to be several mechanisms that allow powdered activated carbon to improve plant performance such as removal of organics by adsorption on the carbon resulting in improved bio-oxidation at these sites. The retention time of organics in the system is also increased.

- **Anaerobic Digestion:** In this process, micro-organisms are allowed to react with the relatively high strength wastes in closed tanks in the absence of air (anaerobic). Hydrolysis and fermentation of the biodegradable organics occur under these conditions resulting in the formation of methane gas and carbon dioxide. An efficiently operating anaerobic digester coverts about 50 per cent of the organic material to liquid and gaseous forms.

- **Enzyme Treatment/Mutant or Adapted Micro-organisms:** These are specialized forms of treatment employing either cell free microbial enzymes which have the capacity to degrade specific toxic organic wastes or mutant or adapted micro-organisms in which their enzyme systems have been "engineered" to cope with and allow the organisms to grow in unusual environments such as hydrocarbons or phenolics in water.

APPLICABILITY OF TECHNOLOGY TO LIQUID INDUSTRIAL HAZARDOUS WASTE MANAGEMENT

Many factors contribute to the applicability to specific wastes of each of the biological treatment processes. These include, the technical performance, economics, environmental impacts, and institutional factors. The technical performance of the process application is measured in terms of its effectiveness in treating the waste, mechanical reliability, sensitivity to input waste changes, and proven application. Economic considerations include capital cost and material, energy, maintenance and labour expenses. Environmental impacts on air and water quality, and subsequent requirements for the treatment and/or disposal of residuals must be considered. Land use, operating staff avilability and training, siting and other institutional factors must also be considered.

Biological treatment processes are principally aimed at the destruction and removal of biodegradable organic substances. Biological treatment is not effective in the destruction of inorganic or non-biodegradable organic wastes, although a significant degree of removal can often be obtained from dilute wastes through physical processes.

All biological treatment requires an aqueous medium to bring wastes and micro-organisms into contact. In general, aerobic biological treatment systems are designed to treat relatively dilute wastes. As a general guideline, wastes with a five-day Biochemical Oxygen Demand (BOD_5) (i.e. the amount of oxygen required to stabilize the biodegradable organics in a 5-day test) should not exceed 10,000 mg/L. If the BOD_5 is higher than this, then consideration should be given to either anaerobic biological processes or non-biological forms of treatment. Some aerobic processes achieve the conversion of wastes within microscopic films of water, e.g. composting and land treatment technologies.

A limitation also occurs at very low substrate concentrations in the waste such as might be encountered where a biological process is used as a "polishing" system following some other form of treatment. The first problem is that the slow substrate utilization kinetics at low concentrations provide too little energy to sustain the micro-organisms. Typical minimum concentrations for aerobic systems have been noted to be in the range of 0.1 to 1.0 mg/L. These threshold value concentrations are frequently higher than the final desired effluent concentrations for hazardous and toxic materials which may be 1 ug/L or less. These limitations at the low concentration levels may be minimized by optimizing the treatment process by, for example, employing powdered activated carbon in the system, by increasing the residence time for treatment and by utilizing co-oxidation or cometabolism effects.

The satisfactory performance of both aerobic and anaerobic biological treatment plants which are treating industrial wastes either as mixtures of domestic sewage and industrial waste or industrial wastes alone is dependent on a number of factors. The presence of toxic chemicals, particularly heavy metals, and toxic organics such as pesticides, can be inhibiting depending on concentration. Metal ions in wastes which are treated aerobically can be retained in the sludge and can be inhibitory to subsequent anaerobic digestion processes. In addition to toxicity factors, biological treatment plants, particularly those treating industrial wastes, can be subjected to fluctuating hydraulic and organic loadings. Pretreatment to remove toxic or high level inorganic materials, neutralization of acids or alkali to keep the pH in the physiological range, equalization basins to smooth shock hydraulic or organic loads are required in many instances when treating industrial wastes biologically. It is also quite common for industrial wastes to be deficient in one or more of the nutrients essential for microbial growth and pollutant removal so that supplementation may be required if satisfactory treatment is to be achieved.

In spite of these disadvantages, it is possible by selecting appropriate processes to satisfactorily treat many industrial wastes in a cost effective manner by biological processes.

Most applications of biological treatment technologies combine physical/chemical and/or other biological processes. These other processes are often employed to pretreat the wastes to make them acceptable for biological treatment, e.g. remove toxic compounds, adjust pH, or equalize waste characteristics.

All biological treatment processes produce residual solids. These solids contain excess micro-organisms (aerobic systems much more so than anaerobic) and any insoluble inorganic and non-biodegradable organic compounds. These sludges are often quite voluminous and are frequently treated. e.g., with heat or chemicals, or by anaerobic digestion, and dewatered. Ultimate disposal of sludges may include incineration, secure landfilling, or, if their composition permits, by land treatment.

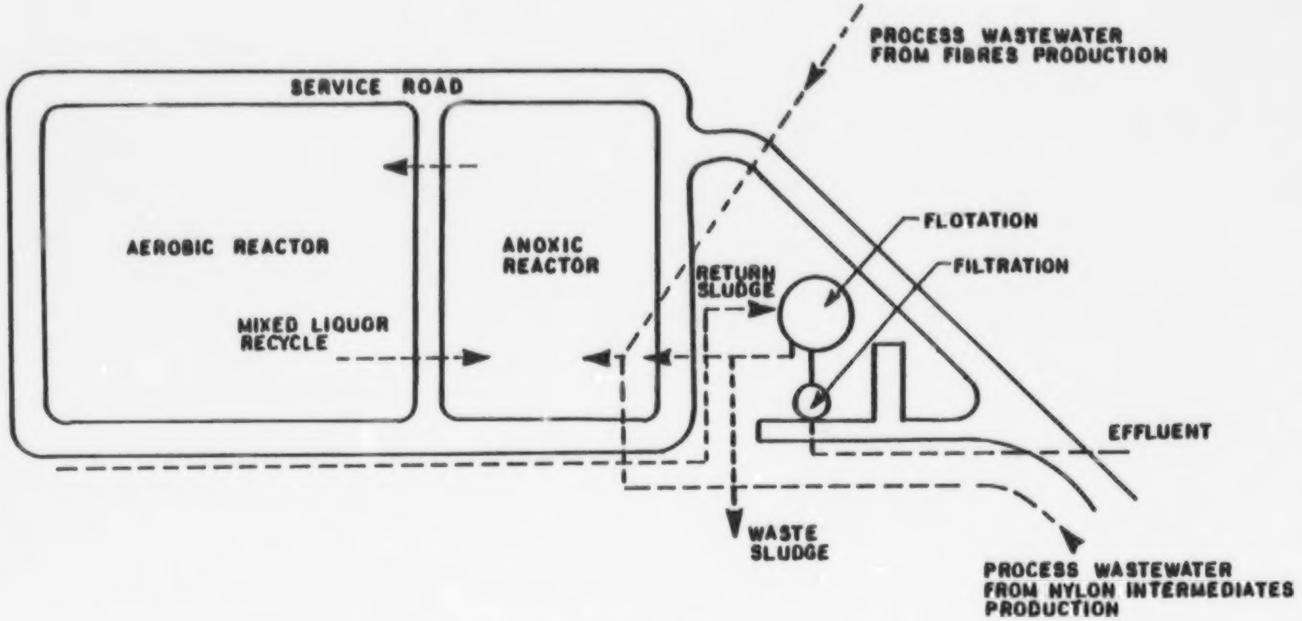
Resource recovery from sludges is possible in many cases. The production and utilization of methane gas by anaerobic digestion realises some of the potential of sludge. The production of compost or even heat from incineration may also be regarded as resource recovery. Greater utilization could be made of sludge if it were regarded as an industrial raw material. Products from sludge which have been suggested are:

Paper	by digestion with chlorine or sodium hypochlorite to solubilise all but the polymeric fraction which can then be treated as a cellulose pulp and a coarse paper material produced.
Adsorbents	by pyrolysis of activated sludge to produce a char which has characteristics between fly-ash and activated charcoal.
Oil	by treatment with carbon monoxide and steam at high pressure and temperature.
Plastic	from the protein fraction of activated sludge.
Animal feeds	by hydrolysis followed by direct feeding or subsequent production of single cell protein from hydrolysates.

Liquid effluent from biological processes may be acceptable for discharge, or may require further attention by physical-chemical or other biological processes.

All biological technologies evolve gases. Aerobic systems produce carbon dioxide and anaerobic processes methane, carbon dioxide and possibly nitrogen. Methane is potentially a valuable by-product and is often recovered. Carbon dioxide and nitrogen are innocuous gases. The potential exists for volatile chemicals to be stripped from certain wastes (e.g., cyanide) and for the production of aerosols from some treatment systems, which in either case may require control, or limit the application of biological treatment.

Figure 3.2.2. presents an example of an integrated biological treatment facility receiving wastes resulting from the manufacture of plastic resins and other organic chemicals. The wastewater, containing high levels of organic



PROCESS WASTEWATER FROM FIBRES PRODUCTION
SERVICE ROAD
AEROBIC REACTOR
ANOXIC REACTOR
MIXED LIQUOR RECYCLE
RETURN SLUDGE
FLOTATION
FILTRATION
EFFLUENT
WASTE SLUDGE
PROCESS WASTEWATER FROM NYLON INTERMEDIATES PRODUCTION

SOURCE: BRIDLE AND JANK, 1980

FIGURE 3.2.2 : INTEGRATED BIOLOGICAL TREATMENT OF ORGANIC CHEMICAL INDUSTRY WASTEWATER

acids, nitric acid, ammonia and organic nitrogen compounds. Raw wastewater is received by an anoxic biological reactor to convert nitrate and nitrite compounds to nitrogen gas in the absence of oxygen via nitrifying bacteria. The aerobic reactor is an aerated lagoon in which organic wastes are metabolized and ammonia and organic nitrogen compounds are converted to nitrate. Part of the mixture of micro-organisms and liquid (mixed liquor) in the aerated lagoon is continuously recycled to the anoxic reactor for denitrification. Some of the mixed liquor is also directed to a flotation tank, wherein the biological solids are separated and most returned to the anoxic reactor. Excess biological sludge is trucked off site. Effluent from the flotation tank is further polished by a dual media filter before final discharge.

ACTIVATED SLUDGE PROCESS

Process Description

The activated-sludge process is a common biological wastewater treatment method and numerous plants are installed in Ontario municipalities for the treatment of domestic sewage or domestic sewage containing some industrial wastes. It is also used by industries such as petroleum refineries, iron and steel complexes, food processors, pulp and paper mills.

In the activated-sludge process, a mixture of wastewater and micro-organisms is agitated and aerated. Under such conditions, micro-organisms typically present in the influent will grow rapidly using the organics, either soluble or solid, in the wastewater as food. As the micro-organisms grow, the individual organisms clump together (flocculate) to form an active mass of microbes called "activated-sludge". Normally, wastewater flows continously into an aeration tank where air is injected to mix the activated-sludge with the wastewater and to provide the oxygen required for the micro-organisms to break down the organics. The "mixed liquor" of micro-organisms and wastewater in the aeration tank is typically aerated for 6 - 8 hours in long, rectangular tanks with about 28 dm^3 of air injected uniformly along the length of the tanks for each gallon of wastewater treated. Air, or in certain treatment systems, oxygen, is introduced either by mechanical mixers located at the surface of the tank or by injection through diffusers located near the bottom of the aeration tank. The "mixed liquor", after aeration, flows to a secondary clarifier where the activated-sludge is settled out. A portion of the settled sludge is returned to the aeration tank to maintain a high population of microbes (2,000 - 3,000 mg/L mixed liquor suspended solids) to permit rapid breakdown of the organics in the incoming wastewater, i.e. the food-to-micro-organism ratio is optimally adjusted. The value of sludge returned to the aeration tank is typically 20 - 30 percent of the wastewater flow. More activated sludge is produced than can be utilized in the process. As a result, some of the return sludge from the secondary clarifier is "wasted" by diverting to a sludge-handling system for treatment and disposal.

Wastewater treatment processes utilizing these principles are:

- **Conventional Activated Sludge**

  Conventional activated-sludge employs the principles described above and is shown in Figure 3.2.3. There are a number of variations of the conventional process such as:

  - **Tapered aeration system.** The discovery that the demand for oxygen in the aeration tank was much greater at the inlet end where the wastewater entered, than at the outlet end where the waste had been stabilized, led to the tapered aeration system. In this system a greater portion of the air is injected at the inlet end that at the outlet end of the aeration tank. The amount of air used is the same but its distribution is proportioned or "tapered" along the tank.

  - **Step aeration process** is somewhat of a misnomer since it involves introduction of the wastewater flow at several points along the aeration tank rather than at a single point. This step feeding of the wastewater (Figure 3.2.4) spreads the oxygen demand over more of the aeration tank, resulting in more efficient use of oxygen. Existing conventional plants are often modified to the step aeration process to increase capacity.

- **"Complete Mix" Activated Sludge**

  Even greater benefits can be achieved with the complete mix activated-sludge concept (Figure 3.2.5) where the influent wastewater is dispersed as uniformly as possible along the entire length of the aeration tank so that the oxygen demand is uniform along the length of the tank.

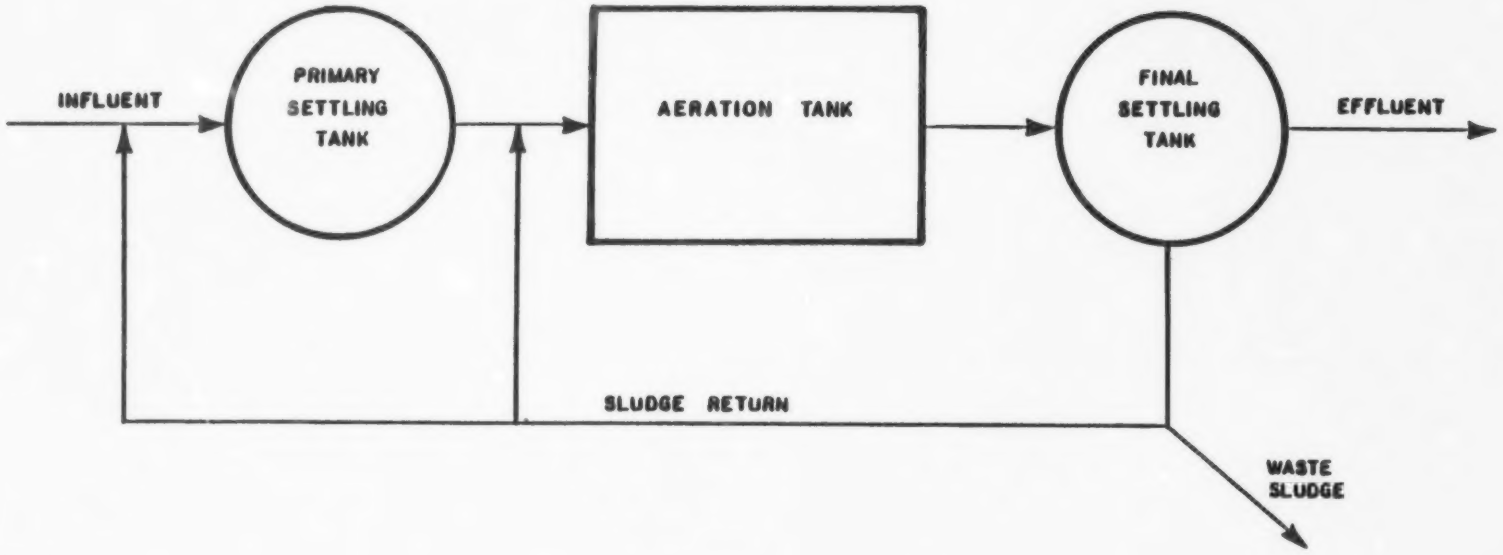

INFLUENT
PRIMARY SETTLING TANK
AERATION TANK
FINAL SETTLING TANK
EFFLUENT
SLUDGE RETURN
WASTE SLUDGE

FIGURE 3.2.3 : CONVENTIONAL ACTIVATED SLUDGE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

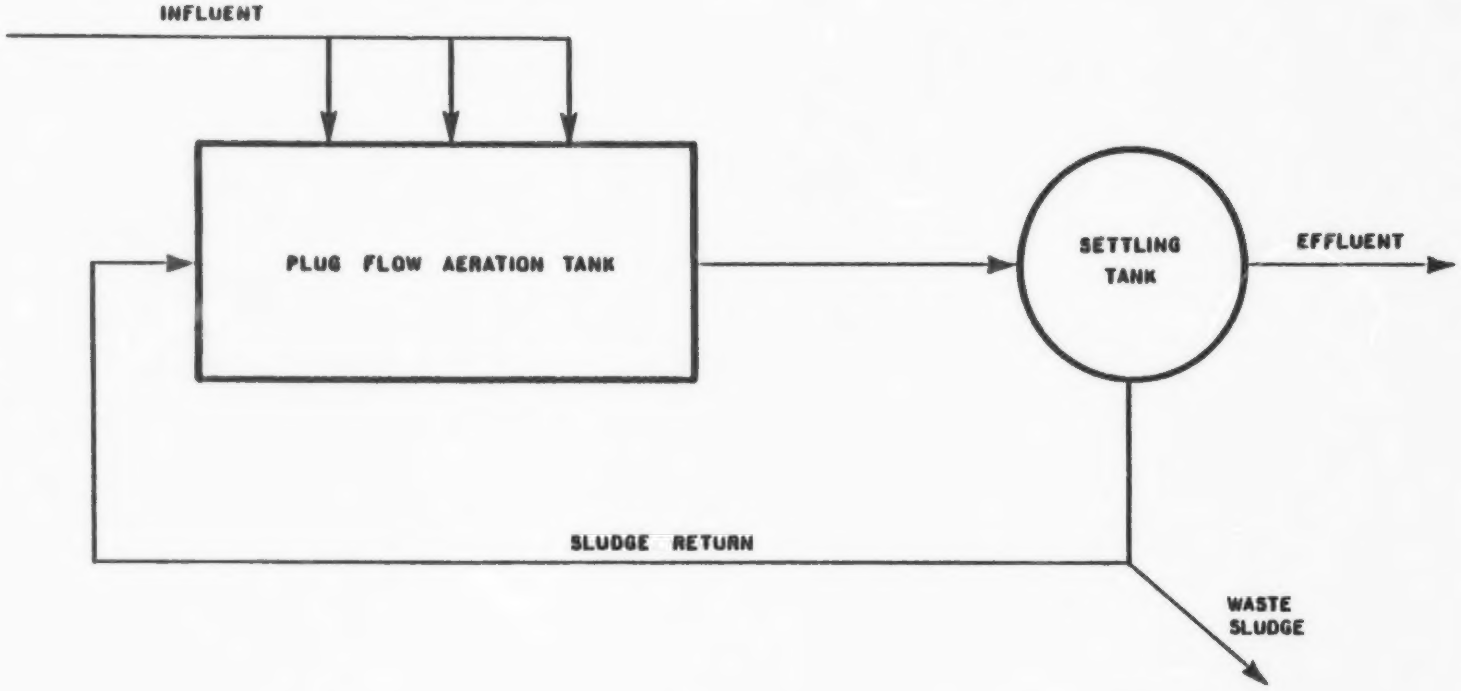

INFLUENT
PLUG FLOW AERATION TANK
SETTLING TANK
EFFLUENT
SLUDGE RETURN
WASTE SLUDGE

FIGURE 3.2.4 : STEP AERATION ACTIVATED SLUDGE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

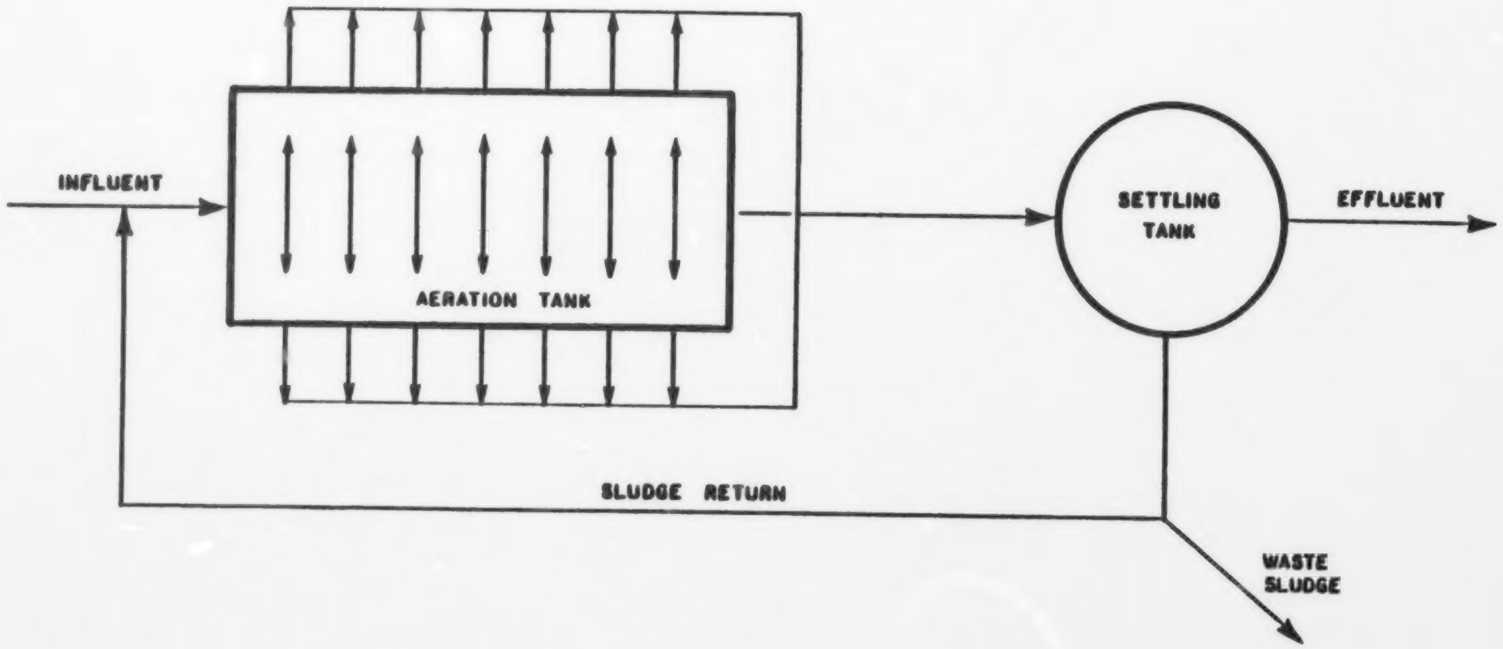

INFLUENT
AERATION TANK
SETTLING TANK
EFFLUENT
SLUDGE RETURN
WASTE SLUDGE

FIGURE 3.2.5: 'COMPLETE MIX' ACTIVATED SLUDGE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

- **Extended Aeration**

  The process flow diagram for this system is essentially the same as in the complete mix system, except that these generally small prefabricated package treatment plants have no primary treatment and the waste is aerated for a 24-hour period rather than the 6 - 8 hours used in conventional plants. The long aeration period allows the activated-sludge formed to be, at least partially, aerobically digested within the aeration tank, thus reducing the need for a large sludge digestion or disposal capacity.

- **Contact Stabilization**

  In this approach the incoming wastewater is mixed briefly (20 - 30 minutes) with the activated-sludge, a period sufficient for the micro-organisms to absorb the organic pollutants from solution, but not long enough for them to degrade the organics. The activated sludge is then settled out and returned to another aerated tank (stabilization tank) in which it is aerated for 2 - 3 hours to allow the absorbed organics to be degraded by the micro-organisms (Figure 3.2.6). Because the settled volume of the activated sludge being aerated is much smaller than the total wastewater flow, the total size of the plant is reduced.

- **Deep Shaft Aeration**

  This process is based on a vertical tubular reactor instead of a conventional aeration tank. A double well casing is used as the reaction vessel (Figure 3.2.7).

Waste Inputs

Activated sludge treatments, whether conventional activated sludge or a variant of the process, are designed to treat relatively dilute aqueous solutions and/or suspensions of biodegradable organic wastes. As a general guideline, the five-day biochemical oxygen demand (BOD_5), i.e., the amount of oxygen required to stabilize the biodegradable organics in a 5-day test,

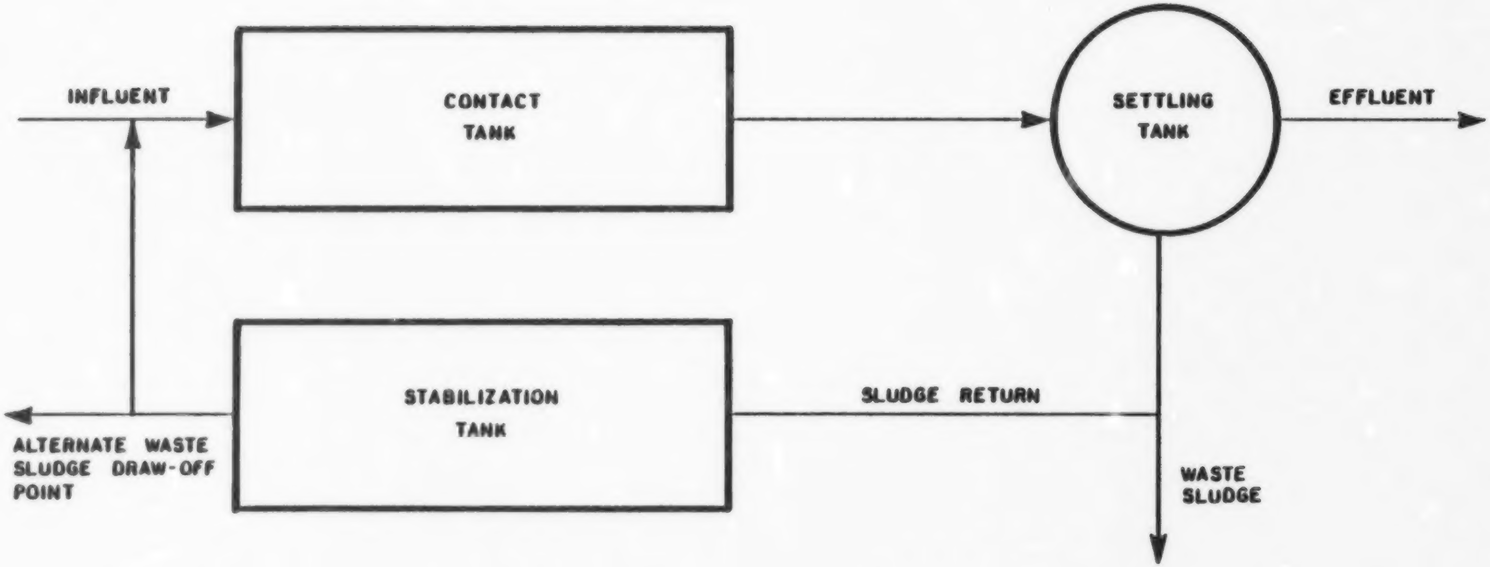

INFLUENT
CONTACT TANK
SETTLING TANK
EFFLUENT
STABILIZATION TANK
SLUDGE RETURN
ALTERNATE WASTE SLUDGE DRAW-OFF POINT
WASTE SLUDGE

FIGURE 3.2.6 : CONTACT STABILIZATION ACTIVATED SLUDGE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

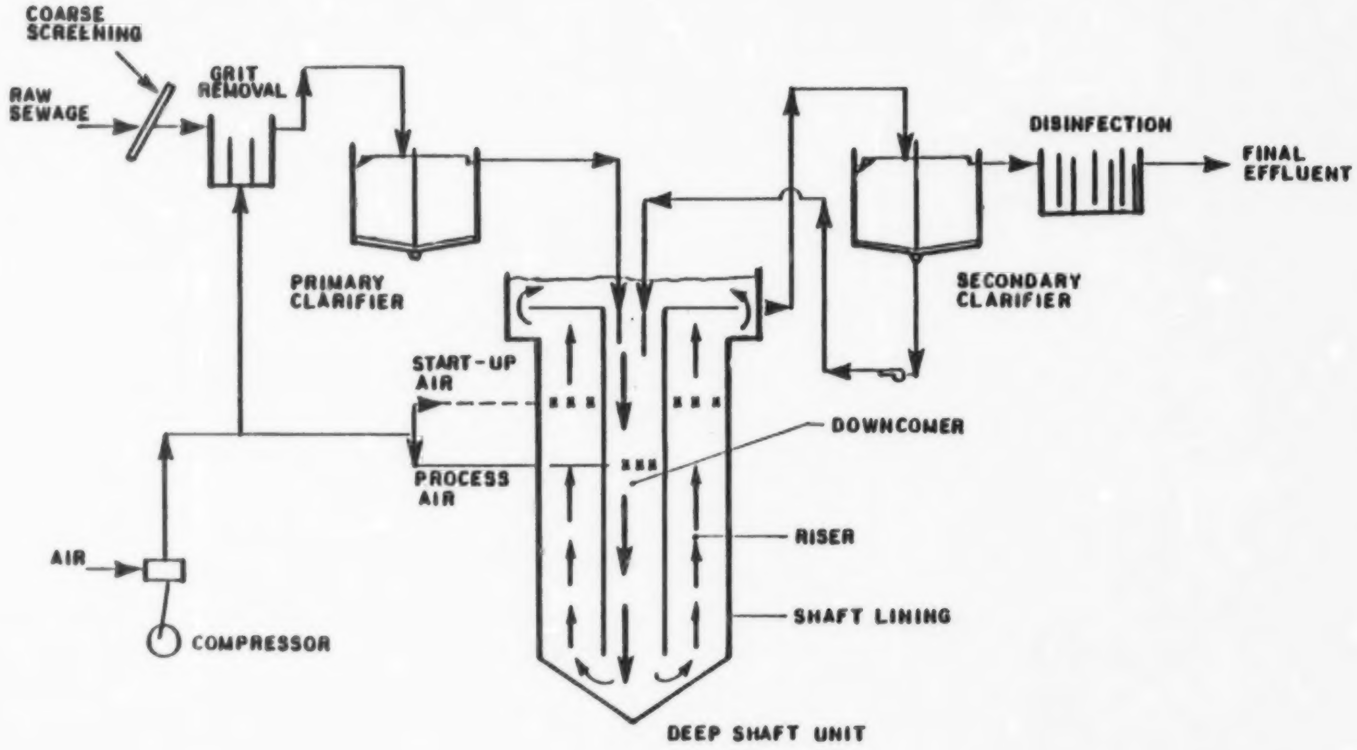

COARSE SCREENING
RAW SEWAGE
GRIT REMOVAL
PRIMARY CLARIFIER
DISINFECTION
FINAL EFFLUENT
SECONDARY CLARIFIER
START-UP AIR
PROCESS AIR
DOWNCOMER
AIR
RISER
SHAFT LINING
COMPRESSOR
DEEP SHAFT UNIT

FIGURE 3.2.7 : DEEP SHAFT ACTIVATED SLUDGE

SOURCE: GALLOW AND SANDFORD, 1979

should not exceed 10,000 mg/L. If the BOD_5 is higher than this, then consideration should be given to either anaerobic biological processes or non-biological forms of treatment or pretreatment. Activated-sludge systems can be acclimated to metabolize quite toxic organic wastes (e.g. phenols) over a period of time. Although micro-organisms can also acclimatize to increasing concentrations of metal ions if sufficient time is allowed, the limit for the more toxic metals, above which there is a significant decrease in treatment efficiency by activated-sludge processes, is less than 10 mg/L (e.g. Ag 0.03; Zn 2 to 10; Ni 1 to 2; Cr^{+6} 1 to 10; Cr^{+3} 10; Pb 10; Fe^{+3} 15; Cu 1 to 10; Cd 1 to 5 mg/L). Such systems do not destroy and, with certain exceptions, do not alter inorganic constituents of the waste stream. High concentrations of inorganics can be inhibitory to the decomposition activity of micro-organisms. Pretreatment (e.g., lime treatment) to remove high levels or toxic levels of inorganics, particularly heavy metals, from a liquid industrial waste and hazardous waste is necessary.

Activated-sludge systems are prone to upset from sudden shock organic, inorganic or hydraulic loads. Employment of equalization basins can assist materially in reducing these effects. Industrial wastes may also be deficient in nutrients, particularly nitrogen and phosphorus and require supplementation to provide a balanced food source for the micro-organisms.

Effluents and Residuals

Excess sludges generated in the treatment process are the major problem. These sludges can be primary sludges and/or secondary sludges and consist entirely of biological solids or be partly chemical and organic sludges. Sludges are produced at various solids content, but are of the order of 5%. The nature of the sludge itself will largely determine which of the available techniques for treatment (thickening or elutriation; conditioning by anaerobic digestion, by heat treatment, wet air oxidation, etc., dewatering mechanically, or by drying on beds or by forced drying with heat) and ultimate disposal (land-fill, long-term lagooning or spreading on agricultural land, incineration) are used. Liquid effluent from activated-sludge treatment of industrial waste is likely to contain quite low levels of biodegradable organics after treatment. Hazardous and toxic organics, although they may be reduced in concentration, may still be present at levels (1 µg/L or less) which are cause for concern.

Inorganics are likely to be lower, perhaps by as much as 40%, in the liquid effluent than in the input waste, but the difference will largely be found in the sludge fraction. Nitrogen levels in the form of ammonia or nitrate may increase in the effluent and may require an ammonia stripping or denitrification step before final discharge when dealing with wastes high in nitrogen. Gaseous emissions from the activated sludge processes are mainly carbon dioxide, nitrogen and water vapour. Volatile organic materials in the incoming waste, such as light hydrocarbons, will be largely lost to the atmosphere during aeration and would, if present in appreciable amounts, require installation of gaseous emission control measures, most probably prior to aeration, unless the aeration tanks are covered.

Implementation, Reliability

All of the activated sludge processes have been widely employed for the treatment of domestic and/or domestic plus industrial wastes, for many years. While the microbiology and biochemistry of the processes are complex, the engineering design is relatively simple and straightforward. Open or closed tanks, reactors or basins are employed for equalization, aeration and clarification. Aerobic conditions are maintained by either mechanical aerators, or by diffusers fed by compressed air. Sludge recycle pumps are used for return of sludge from the clarifiers to the aeration tanks.

If the system is protected against both hydraulic and organic shock loads and the pH and heavy metal content is maintained within the capacity of the system, biological treatment employing activated sludge may be expected to be reliable. In very cold weather, some problems from icing may be encountered, for example, with mechanical aeration equipment the removal efficiencies may be reduced with sharp drops in temperature. Gradual temperature changes are less of a problem because there is time for adaptation.

Process Applications

Application of activated sludge processes to domestic and domestic plus industrial liquid wastes are extensive. Purely industrial applications in Ontario may be found in the treatment of coke oven wastes containing phenols and cyanides from the iron and steel industry, pulp and paper mill wastes, refinery wastes, textile wastes and pharmaceutical wastes, as well as the more readily biodegradable wastes from food industries and breweries.

Laboratory studies have indicated that biodegradation of hazardous organic compounds such as polynuclear aromatic hydrocarbons can be accomplished. Very recently, the U.S. EPA and the Chemical Manufacturers Association released data on a joint study on five chemical manufacturing plants employing well-designed and well-operated activated sludge treatment systems. The results from approximately 30 sets of influent and effluent data indicate that 95% volatile toxic organic pollutants, 87% of the base/neutral extract fraction and 77% of the acid extract portion are removed. Of the 52 individual toxic organic pollutants in the effluent streams, 36 were detected at mean concentrations below 10 µg/L, 10 were between 10 and 50 µg/L and 5 were between 50 and 100 µg/L, and only 1 was over 100 µg/L.

Economic Considerations

The capital and operating costs for an activated sludge have been estimated as \$6,600/kg BOD_5 applied daily and \$0.40/kg BOD_5 applied respectively.

Energy Requirements

Electrical energy is required to operate pumps, aeration equipment. Typically, 625 kWh per 3,780 m^3 treated is required.

Resource Recovery Potential

Aerobic systems treating industrial wastes generate fairly large quantities of waste biological sludge which contain non-biodegradable inorganics and refractory organics. If the sludges are treatable by anaerobic processes, a methane credit can be obtained or, if dewatered and incinerated, some energy in the form of heat can be recovered.

Environmental Factors

Unless plant upsets occur, odours are not usually a problem, but loss of volatile organics from open aeration basins could result in environmental problems with industrial wastes containing appreciable volatile organics. The largest single problem with activated sludge is obtaining satisfactory disposal of the surplus sludges. In some instances, where influent wastes are high in nitrogen, ammonia stripping or a denitrification step may be required to lower the ammonia or nitrate levels in the effluent to 10 mg/L nitrogen or less before discharge.

ACTIVATED SLUDGE SYSTEMS USING PURE OXYGEN

Process Description

Pure oxygen may be used as a substitute for air in activated sludge systems. To provide efficient use of the oxygen, the aeration tanks are often covered and the oxygen recirculated through several stages (Figure 3.2.8). With covered tanks. oxygen is introduced into the headspace in the first aeration stage and flows through the various stages concurrently with the waste. Mixing within each stage is accomplished either with surface aerators or with a submerged rotary sparging system. Alternatively, particularly with uncovered basins, specially designed efficient oxygen diffusers may be used. The oxygen used in the process is typically generated onsite. The use of high purity oxygen increases the rate of oxygen transfer and, by staging the process, 85 - 90% of the oxygen gas fed can be utilized. The use of oxygen also enables maintenance of high dissolved oxygen (DO) levels in the mixed liquor (5 - 8 mg/L) resulting in a highly aerobic biomass which flocculates and settles very well. The high DO levels in the mixed liquor and higher mixed liquor suspended solids (MLSS) level enables treatment to be carried out at higher sludge loadings. Retention times are much lower (1½ - 2 hours) than air system retention times (6 - 8 hours) and the aeration tanks are smaller.

Waste Inputs

The combination of high MLSS levels at high DO levels provide a buffer of oxygen and biomass which can cushion sudden changes in organic load. This, combined with the high oxygen dissolution capacity and the method of feedback pressure control of oxygen possible with closed vessels, makes the system quite resistant to shock organic loads when compared to air activated-sludge systems. This characteristic makes pure oxygen systems particularly suitable for industrial waste streams where sudden changes in loading are common occurrences. Apart from increased tolerance to shock organic loads, similar constraints on heavy metal content, pH, etc., apply to the pure oxygen activated-sludge plants as those for conventional air plants.

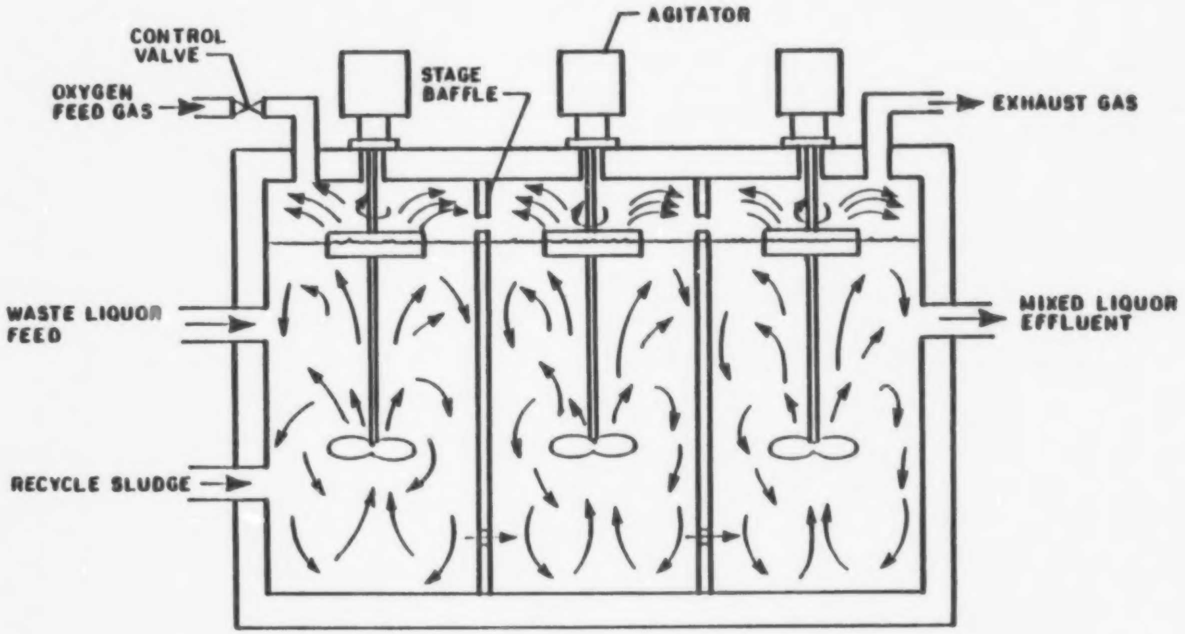

CONTROL VALVE
OXYGEN FEED GAS
STAGE BAFFLE
AGITATOR
EXHAUST GAS
WASTE LIQUOR FEED
MIXED LIQUOR EFFLUENT
RECYCLE SLUDGE

FIGURE 3.2.8 : MULTISTAGE OXYGEN AERATION SYSTEM

(ACTIVATED SLUDGE)

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

Effluents and Residuals

Liquid effluent from pure oxygen activated-sludge plants should be the same, if not of better quality, than those from corresponding activated-sludge plants operating with air, even though pure oxygen plants are operated at higher food to micro-organism ratios. The higher DO levels in the aeration tanks appear to promote oxidation of organics which either are degraded only slowly or not at all at the lower DO levels in conventional air systems. The flocculation and dewatering characteristics are better with pure oxygen systems. Closed top reactor pure oxygen systems and the inherent low vent gas flow (less than 1% of that of an air system) would be a definite advantage in eliminating or controlling any odour or volatile organics and mist problems.

Implementation, Reliability

Since introduction of the first pure oxygen system in 1970, over 50 full-scale industrial plants treating a wide variety of wastewaters have been built and operated. In addition, feasibility trials at bench or pilot-scale have been conducted on most biologically treatable industrial wastewaters to demonstrate performance capabilities and establish design parameters for application to full-scale plants. The increased resistance to shock load and the instantaneous response to oxygen demand changes through pressure control type systems is particularly advantageous for treatment of industrial waste over air activated systems. Sustained toxic loading would, of course, as with other biological treatment systems, eventually kill the micro-organisms.

Process Applications

Pure oxygen activated-sludge systems have been used for the treatment of chemical wastes containing water repellants, surfactants and elastomers, unbleached kraft liquors (as a secondary step) and pharmaceutical wastes. Pure oxygen plants are ideal for the treatment of highly concentrated industrial wastes or wastes containing reducing or inhibitory materials which can only be treated by a large, highly active, activated-sludge process.

Economic Considerations

The higher capital costs for oxygen production is largely offset by reduced aeration tank size requirements and improved waste sludge handling characteristics and volume. Space savings alone can sometimes justify an oxygen system. Capital and operating costs have been reported as \$6,400/kg BOD_5 applied daily, and \$0.51/kg applied, respectively for covered systems.

Energy Requirements

In addition to the normal energy demands for dissolution of oxygen, the energy and costs for the production of oxygen must be added. In small plants oxygen is supplied in liquid form. For larger plants, oxygen is produced on site by using molecular sieves as pressure swing adsorbers (PSAs) for capacities up to 30 tonnes/day and cryogenically for plants above 10 or 20 tonnes/day.

Resource Recovery Potentials

Apart from methane values from the anaerobic decomposition of excess sludge or heat values from incineration of dewatered sludge, there is little potential for resource recovery.

Environmental Factors

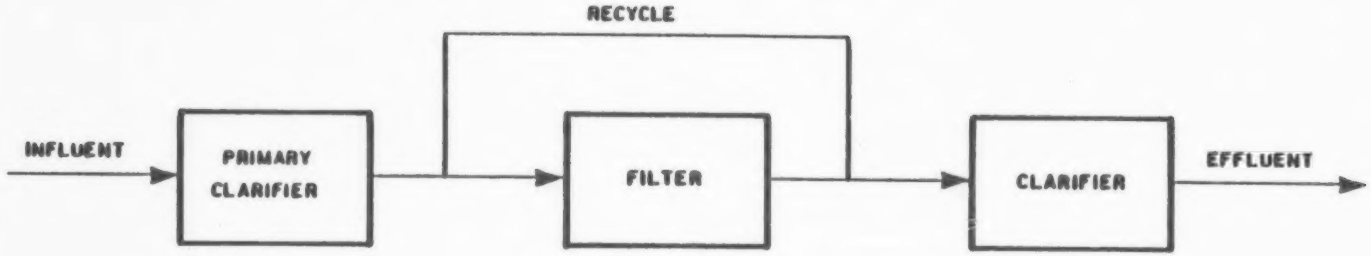
Control of possible gaseous problems such as volatile or odourous material stripped from the waste during aeration would be easier with pure oxygen systems using closed tanks, but special precautions must be taken to avoid accumulation of inflammable volatile materials in the headspace atmosphere of the tanks. Reduced sludge volumes and ease of dewatering of pure oxygen dewatered sludges would reduce bulking problems in the ultimate disposal of a sludge.

TRICKLING FILTERS

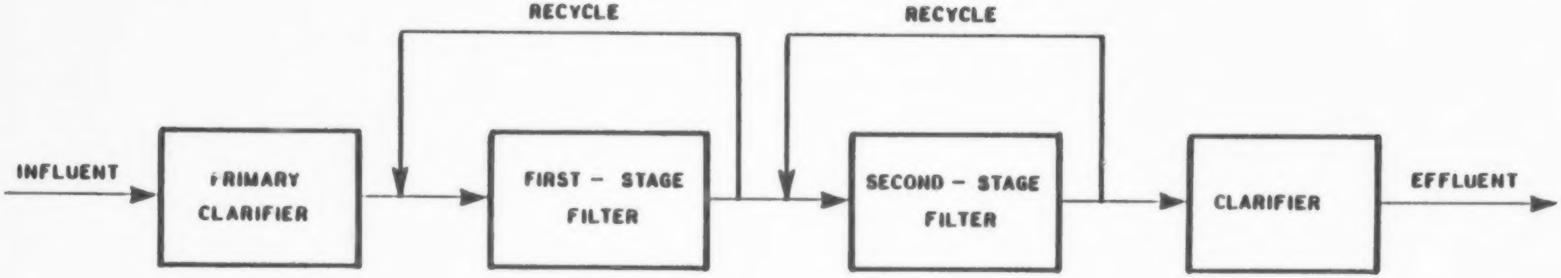
Process Description

A trickling filter is really a three-phase fixed bed reactor. Wastewater is applied at the top of a fixed bed or tower of porous media such as stones, slats or plastic material, through which an upward flow of air passes. Microorganisms gather and adhere to the media, utilizing the oxygen and the organics dissolved in the liquid phase as food. Excess growths of microorganisms, which slough off from the media, flow out via underdrains with the treated effluent to a clarifier to allow these solids to settle out. The under-drain system is also used to provide natural-draught aeration to the media. These are two important factors in the operation of a trickling filter. The first requirement is for a high specific surface area for microbial colonisation and therefore organic load removal. The second requirement is for a certain degree of void volume to allow circulation of air in the filter and to prevent growths plugging the interstices of the filter. Modern trickling filters, especially those for treatment of high strength industrial wastes, use towers packed with plastic medium which offer a large surface area and greatly increased void ratios. In order to control excessive film growth, recirculation of effluent or alternating double filtration are used. Two-stage filtration may also be used for this purpose. When recirculation is employed the incoming waste is diluted with settled effluent prior to application to the filter (Figure 3.2.9a). Ratios in excess of 2:1 may be employed with strong industrial wastes. This has two effects: firstly, the available food is reduced resulting in growth limitation; and secondly, the higher scouring rates resulting from increased hydraulic flow removes any loose film.

When alternating double filtration is employed using two sets of filters and settling tanks in series, wastewater is applied to the first filter at a high rate and the microbial film is allowed to grow rapidly, whereas there is little accumulation on the second filter which is being loaded lightly. The sequence is then reversed and the accumulated film in what was the first filter is rapidly depleted.


RECYCLE
INFLUENT
PRIMARY CLARIFIER
FILTER
CLARIFIER
EFFLUENT

a) ONE - STAGE


RECYCLE
RECYCLE
INFLUENT
PRIMARY CLARIFIER
FIRST - STAGE FILTER
SECOND - STAGE FILTER
CLARIFIER
EFFLUENT

b) TWO - STAGE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

FIGURE 3.2.9 : TRICKLING FILTER SYSTEMS

In two-stage filtration, the concept of sequential high and low rate application is also used, but in this case the primary filter employs a coarse media filter which can be operated at a high loading rate without clogging. The secondary filter with conventional packing is operated under nutrient limited conditions and is capable of producing a good quality effluent without risk of plugging and ponding of the filter. The flow through the filter is not a continuous process since wastewater is applied as drops, films or sprays from moving distributors or fixed nozzles. The optimum dosing frequency for obtaining best liquid-film contact is a function of the waste being treated and of the ambient temperature in the filter. (Figure 3.2.9b).

Waste Input

Trickling filters decompose all types of organics in a similar way to activated sludge treatment. The percentage removal of organics is not as complete as in activated sludge; typical removal efficiencies are around 85 percent owing to the relatively short residence times. Sometimes the systems are used as roughing filters to reduce concentrations of biodegradable material prior to other biological processes. However, the short residence time characteristic does confer some flexibility to variations in spent wastes since shock organic loads and inhibition by metals concentrations are less likely to cause upset of the process. Organic loading rates usually depend on the quality of the final effluent required and the nature fo the raw waste. In general, these are in the range 0.5 to 6 kg BOD/m^3/day.

Effluents and Residuals

Final effluents are usually not as good as those from activated sludge plants unless very low loading rates are employed. Excess sludges collected in final clarifiers require disposal in a manner similar to the activated sludge process.

Implementation, Reliability

The basic simplicity of the process is an advantage and the incoming waste load of pollutants can vary over a wide range without causing operating problems, thus minimizing the need for operator skills. The mechanical equipment is simple, thus easing maintenance. The process efficiency is affected markedly by air temperature because of the large fixed surface area of the microbes exposed to the air so that in many parts of Canada unsatisfactory operation may occur unless special precautions are taken.

Process Applications

Industrial applications of trickling filters have been for the treatment of refining wastes containing oil, phenol and sulphides, a multitude of food processing effluents, plastic manufacturing wastes and dyehouse wastes and for partial treatment of pharmaceutical wastes.

Economic Considerations

Total capital costs of about \$4,700/kg BOD_5 applied daily, and operating costs of \$0.23/kg BOD_5 applied for a high rate, rock media trickling filter.

Energy Requirements

The process has low power consumption, about 150 kWh per 3,780 m^3 treated.

Resource Recovery

Anaerobic treatment of surplus sludge generated can generate a methane credit.

Environmental Factors

The complex predator-prey food chains which exist within a filter bed include fly larvae. At certain times of the year the adult flies can be a nuisance in the surrounding area. In addition, at high loading rates a certain degree of anaerobisis exists, particularly in primary filters which can lead to odour problems.

The space requirements for rock media filters is about 5350m^3 for 5000m^3/day capacity and for tall plastic filled filter towers about 2670m^3 for 5000m^3/day capacity.

ROTATING BIOLOGICAL CONTACTORS (RBC)

Process Description (Figure 3.2.10)

The rotating biological contactor process consists of a series of closely spaced flat or lattice structure plastic discs (usually about 3.0 - 3.5 m in diameter) mounted on a horizontal shaft. The discs are rotated so that one half of their surface is immersed in the wastewater. As the discs rotate in the wastewater, microbes adhere to the surfaces of the discs and grow until the entire surface is coated with a biological slime layer. The discs, as they rotate, carry a film of wastewater into the air where it trickles down the surface of the discs absorbing oxygen. As the discs complete their rotation, this film mixes with the reservoir of wastewater adding to the oxygen in the reservoir and mixing the treated and partially treated wastewater. While the attached microbial film passes through the reservoir, organics are absorbed and undergo breakdown. The biomass film develops to about 2 - 3 mm thickness over the whole rotating surface area. It is estimated that the biomass layer, if removed and suspended in the mixed liquor, would be equivalent to approximately 10,000 to 20,000 mg/L suspended solids concentration. It is this large microbial population which allows achievement of a high degree of treatment within a relatively short treatment time (1 - 2 hours). Substrate removals per unit area may be two to three times higher than static fixed film systems. As the treated wastewater flows through the reservoir, excess biological growths shear off from the rotating discs and are carried downstream to a settling tank for removal. Rotation of the disc assemblies can be achieved by a motor and drive system or by air drive with coarse bubble diffusion and air cups attached to the disc periphery. Speeds of rotation are quite low, i.e. 0.5 to 2 rpm.

Waste Inputs

The usual constraints which apply to other biological methods also apply to RBC processes, i.e., pH in the range of 6.5 to 8.5, temperature 10°C to 32°C, and a nutrient balance of BOD:N:P of 100:5:1. At temperatures above

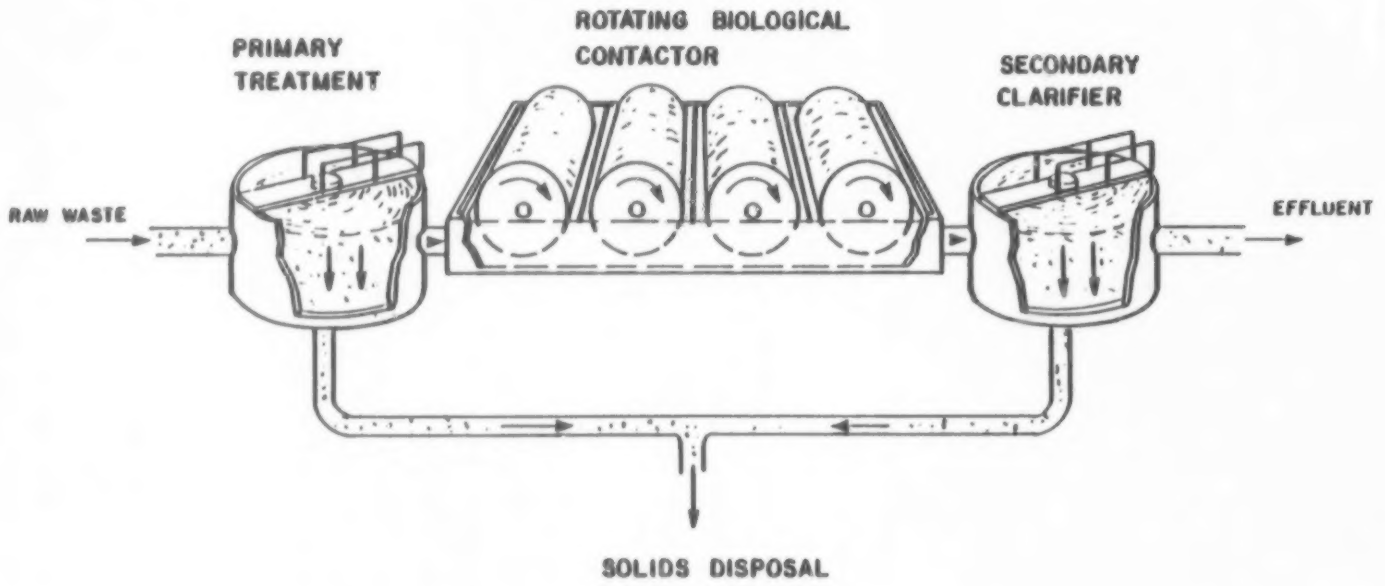

ROTATING BIOLOGICAL CONTACTOR
PRIMARY TREATMENT
SECONDARY CLARIFIER
RAW WASTE
EFFLUENT
SOLIDS DISPOSAL

FIGURE 3.2.10 : ROTATING BIOLOGICAL CONTACTOR

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1976

32°C, there may be difficulties associated with the materials of construction. The RBC is less susceptible to upset from fluctuations in hydraulic and organic shock loads than suspended growth (activated-sludge) systems and is also quite resistant to toxic shock loads because of the large biomass carried in the system. Although BOD in the effluent may increase and BOD removal efficiency decrease under shock load, recovery is rapid because the biomass is fixed and there is no sludge recycle and therefore no loss of active biomass from the system.

Effluents and Residuals

The effluent from the RBC stage generally contains 100 - 150 mg/L of suspended solids so that the solids loading on the clarifier is quite low. Consequently, final effluents are low in suspended solids even at high overflow rates from the clarifier. Sludge production is in the range of 0.4 to 1.0 kg per kg of BOD removal and may be anaerobically digested or disposed of in similar fashion to sludges from other biological processes.

Implementation, Reliability

The design criteria for the RBC process is well developed and supported by a large body of pilot-scale and full-scale operating data. The mechanical equipment is slow speed, thus easing maintenance. There are no sludge or effluent return stream pumps. Effluent quality is equal to or better than suspended growth systems. The bulk of the microbial population is attached to the discs making them less susceptible to wash out and upset than in an activated sludge plant. They require less operational attention and fewer process decisions by the operators than does activated sludge. The disc process must be covered to protect against freezing and in very cold temperatures. the treatment building should be heated if efficiency is to be maintained. Intermittent flow patterns with shut-down of operations at night or during five-day week operation may cause problems with the biomass becoming anaerobic or drying out. Continuous rotation of the discs at reduced speed plus recycle of effluent from the clarifier is one way of avoiding this problem. There are hundreds of RBCs in operation around the world for treating municipal and industrial effluents. Most of these have been installed in the last 10 years. Long-term operating experience is, therefore, limited.

Process Applications

Industrial applications for RBCs have encompassed the wastes from food processing, chemicals/pharmaceuticals, refinery/petrochemical, munitions, textile/dyestuffs, leather, pulp and paper and mining industries. The use of anaerobic RBCs (AnRBC) has been tried successfully at the benchscale for the treatment of high strength carbonaceous wastewaters.

Economic Considerations

The RBC processes appear to be cost-competitive with activated sludge processes. Total capital costs of approximately \$3,700/kg BOD_5 applied daily and operating costs of \$0.42/kg of BOD_5 applied are estimated.

Energy Requirements

Power requirements are approximately 400 kWh/mg treated which compares favourably with approximately 625 kWh/mg for activated-sludge plants.

Resource Recovery Potentials

Methane recovery from the surplus sludge of aerobically operated RBCs and from anaerobically operated RBCs is feasible.

Environmental Factors

Since the units are covered, RBCs have, or could have, advantages over other biological processes with regard to fly nuisances, foam control, odour control, etc. Land requirements are also less (approximately $3000m^2$ per $5000m^3$/day capacity) than most other fixed film systems unless tall packed towers are used.

FLUIDIZED BED WASTEWATER TREATMENT (AEROBIC) SYSTEMS

Process Description (Figure 3.2.11)

These are high rate processes for biological treatment of liquid wastes. The main part of the system is a vertical column filled with a medium such as sand. Wastewater, which is pre-oxygenated for aerobic operation of the bed, is introduced into the bottom of the column via a distribution plate at a flow rate of 420 L to 1100 L/m^2 of reactor cross section. This rate ensures the continous fluidization of the bed and eliminates packing of solids and clogging of the reactor. A microbial layer builds up and coats the surface of each discrete particle of the medium resulting in very high biomass concentrations (12,000 - 40,000 mg/L of volatile suspended solids (VSS)) being carried in the reactor. During operation, the medium expands to about twice the collapsed height. Solids reaching the upper level of the bed are pumped to a solids separation device where the sand coated with micro-organisms is sent back to the reactor and any sloughed-off film that is separated from the sand is directed as a waste sludge stream containing 1 to 3% solids.

The very large surface to volume ratio (3,000 m^2 per m^3) of the fluidized bed compares very favourably with other fixed film reactors such as the rotating disc biological reactor, for trickling filters (160 m^2 per m^3 and 80 m^2 per m^3). The biological mass of 12,000 to 40,000 mg/L compares with about 5,000 mg/L for a pure oxygen activated sludge system and about 2,000 mg/L for suspended growth systems. The number of kg of BOD removed per m^3 of reactor volume is also favourable as seen in the comparison listed below:

Fluidized bed system	16 kg/m^3
Pure oxygen system	3.2 kg/m^3
Suspended growth system	0.8 kg/m^3
Rotating biological reactor	0.8 kg/m^3
Trickling filter	0.4 kg/m^3

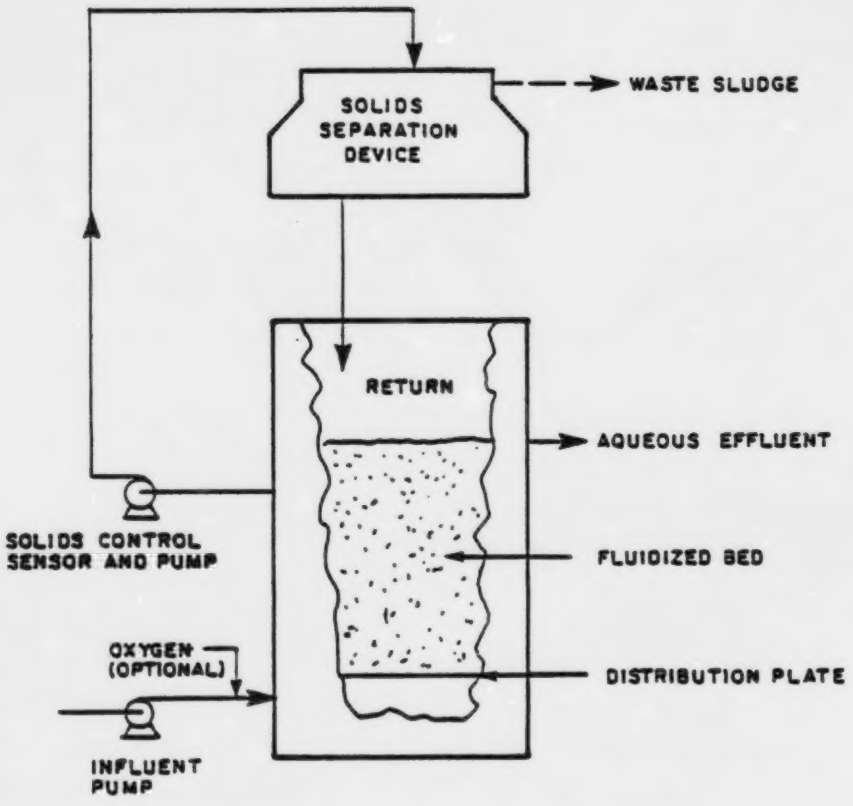

WASTE SLUDGE
SOLIDS SEPARATION DEVICE
RETURN
AQUEOUS EFFLUENT
SOLIDS CONTROL SENSOR AND PUMP
FLUIDIZED BED
OXYGEN (OPTIONAL)
DISTRIBUTION PLATE
INFLUENT PUMP

FIGURE 3.2.11 : FLUIDIZED BED SYSTEM

SOURCE: SUTTON ET AL., 1979

Waste Inputs

The fluidized bed process can be used for aerobic carbonaceous BOD removal and nitrification, anaerobic carbonaceous BOD removal and denitrification of industrial and municipal wastewaters. In aerobic systems oxygen is supplied to the influent distribution system and allows transfer of at least 50 g/m^3 of O_2. If the oxygen demand of the incoming waste exceeds the quantity of O_2 available, dilution by using effluent recycle water would be required. The design parameter used in sizing the fluidized bed reactor is the reactor solids retention time (SRT) or the food to mass (micro-organisms) F/M ratio.

Effluents and Residuals

Pilot plant studies on corn milling wastes indicate that at volumetric loading rates of 12 to 18.4 kg BOD_5/m^3d, BOD_5 removals were between 83 and 94 percent. These are loading ratios which are six to eight times greater than air activated sludge systems. Final effluents would, therefore, still have appreciable BOD_5 at high input loadings even though excellent reduction percentages are being achieved. Filtration or further biological treatment might be required to lower the BOD_5 values to acceptable values for discharge. The sand-biomass separation system would have two streams with the separated sand being returned to the reactor and the excess biomass wasted. This excess biomass would be treatable by the various methods available for other waste biological sludges.

Implementation, Reliability

The fluidized bed system for biological treatment, although attractive, has not been widely employed. Most studies have been at the bench or pilot plant level. The critical factor appears to be in controlling bed expansion in order to prevent the sand-biomass particles being carried over or washed out. This is probably not easy because as the biofilm thickness increases and the sand particles diameter increases, their effective density is reduced. The ability of the sand-biomass separator to handle varying loads is a key factor. With varying input loads it may be difficult to achieve steady state conditions in the reactor. It would appear that the system holds most promise for constant high organic loadings.

Process Applications

Industrial applications for the fluidized bed process which have been suggested or tried are food wastes, coke oven and coal conversion effluents (phenols and thiocyanates), brewery and munitions manufacturing plant.

Economic Considerations

Although a capital cost advantage for fluidized bed systems is implied in the higher volumetric loadings, no full-scale plant data is available.

Energy Requirements

Energy for the production of oxygen, biomass separation and feed and recycle pumping is required. These have been estimated as follows for a plant treating 3,780 m^3/day and a waste concentration of only 3 kg/m^3 BOD_5 for comparison with activated sludge systems.

Oxygen generation	212 kW
Feed and recycle	179 kW
Biomass separation	15 kW
Total	416 kW

For an activated sludge system operating under the same flow and loading characteristics, total energy consumption has been calculated to be 493 kW (aeration 433 kW, sludge recycle 60 kW).

Resource Recovery Potentials

Anaerobic treatment of surplus sludge could create a methane credit.

Environmental Factors

No adverse environmental factors from an aerobically operated system would be anticipated.

LAGOONS (STABILIZATION PONDS) AND AERATED LAGOONS

Process Description (Figure 3.2.12)

Stabilization Ponds

A lagoon is a relatively shallow pond contained within earthworks of controlled shape for the treatment of wastewater. The term "oxidation pond" is often used and is synonymous. Typically, raw wastewater enters the pond at a single point in the middle of the pond or at one edge. The ponds are deep enough (0.6 - 1.2m) to prevent weed growths but not deep enough to prevent mixing by wind currents. Shallow ponds are usually aerobic through nearly all of their depth with only the sludge layer at the bottom of the pond being anaerobic. Deeper ponds with depths of 3 - 6m feet have a larger anaerobic zone. Ponds are usually constructed to accommodate from 15 to 60 days of wastewater flow and may be batch operated (i.e., fill and draw) or continuous (flow-through) operation. A treated system frequently consists of several ponds in a series/parallel arrangement. Algae grow by taking energy from sunlight and consuming carbon dioxide and inorganic compounds released by the action of bacteria in the pond. In turn, the algae release oxygen needed by the bacteria to supplement the oxygen introduced into the pond by wave action. Sludge deposits from the pond eventually must be removed by dredging.

Aerated Lagoons

In order to reduce dependence on algae produced oxygen and to reduce the area required by the ponds, aeration equipment in the form of mechanical aerators or diffused air may be used to supply oxygen. Aerated lagoons are, therefore, a form of the activated-sludge process, but in this case, a second-stage pond is used to remove the suspended solids from the aerated lagoon instead of a clarifier with recirculation. A typical aerated lagoon is relatively deep 1.8 - 3.6 m) and depending on the degree of aeration, has a retention time of two to four days. Depending on the loading and degree of aeration, lagoons may be truly aerobic or partially aerobic-anaerobic (facultative) so that a combination of aerobic-anaerobic microbial processes may occur.

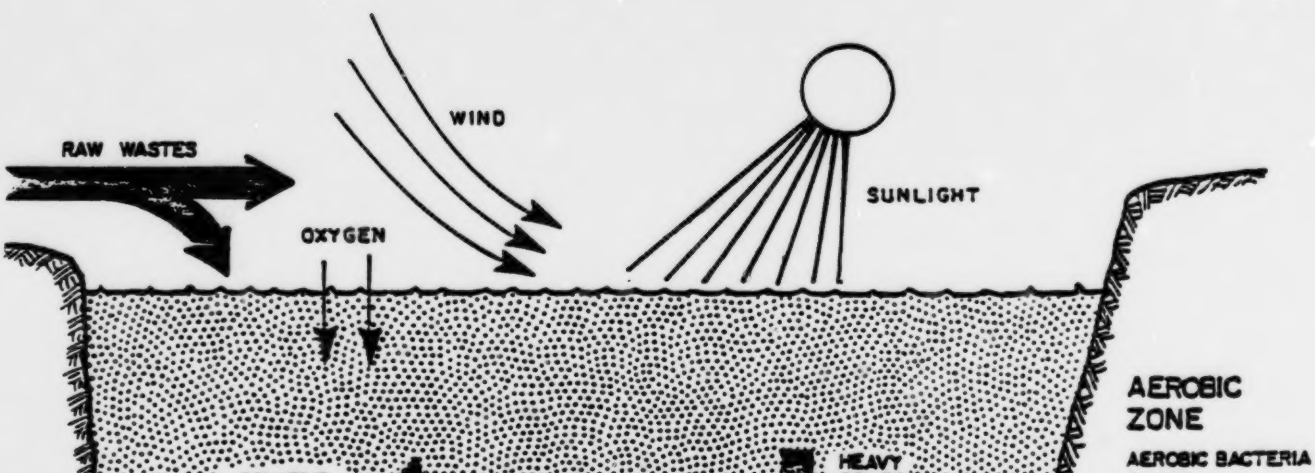

RAW WASTES
WIND
OXYGEN
SUNLIGHT
AEROBIC ZONE
AEROBIC BACTERIA
ALGAE
SOLUBLE ORGANICS
CO_2
H_2S
NH_4
HEAVY SOLIDS
CO_3
NO_3
SO_4
ANEROBIC ZONE
ACID FORMERS
METHANE FORMERS

FIGURE 3.2.12 : LAGOON OPERATION (NON-AERATED)

Waste Inputs

The range of waste inputs is similar but at generally lower concentrations than those acceptable for activated sludge treatment. Aerated lagoons are dilute activated sludge processes so that the range of acceptable concentrations is lower unless anaerobic conditions and long retention times can be tolerated. Since there is no sludge recycle and the mixed liquor suspended solids (biological sludge) is lower, the average removal efficiencies, adaptability to various wastes, and resistance to shock loads are lower. Where very long retention times are employed, biodegradation of refractory organics may occur.

Effluents and Residuals

Liquid effluents are likely to be higher in suspended solids than activated sludge plants unless a polishing system such as a sand filter is employed to remove mainly algae from the pond effluent. Sludge deposits from the ponds must be eventually removed by dredging. Odours can be a problem with oxidation ponds and aerated lagoons which operate with minimal aeration.

Implementation, Reliability

Oxidation ponds are easy to construct operate and maintain. They are low in construction costs and in the case of non-aerated ponds, do not involve mechanical equipment maintenance. The relatively large space requirements for conventional ponds is a disadvantage in many cases.

The actual requirements depend on the climate, but typically range from 19ha per 5000m^3/day of capacity for non-aerated ponds in warm climates to 45ha per 5000m^3/day in cold climates, using approximately 1.2m deep lagoons. Aerated ponds would be about one fifth this size.

Process Applications

The process has been operated successfully on petrochemical wastes, textile wastes and refining wastes. The process is not considered satisfactory for wastewater with highly variable organic and metal concentrations or for wastewater with high concentrations of solids.

Economic Considerations

The construction costs for a pond range from about \$800 per ha for ponds larger than 10 ha, to \$2,400 - \$4,000 per ha for ponds of 16 ha or less - excluding land costs. Operating and maintenance costs are lower than those for trickling filter or activated-sludge plants. Capital and operating costs would be about \$730/kg BOD_5 applied daily and operating costs of \$0.03/kg BOD_5 applied respectively for an anaerobic lagoon and for aerated lagoons \$1,600/kg BOD_5 applied daily and \$0.17 kg/BOD_5 applied.

Energy Requirements

Unless artificially aerated, oxidation ponds do not consume power. Completely mixed lagoons can use more energy than the corresponding activated sludge process.

Resource Recovery Potential

None, unless sediments contain recoverable materials, e.g. metals.

Environmental Factors

Facultative or anaerobic operation can lead to objectionable odours such as hydrogen sulphide. The relatively large space requirements occupy potentially useful land. Disposal of dredged material and/or closure of the lagoon may pose problems.

COMPOSTING

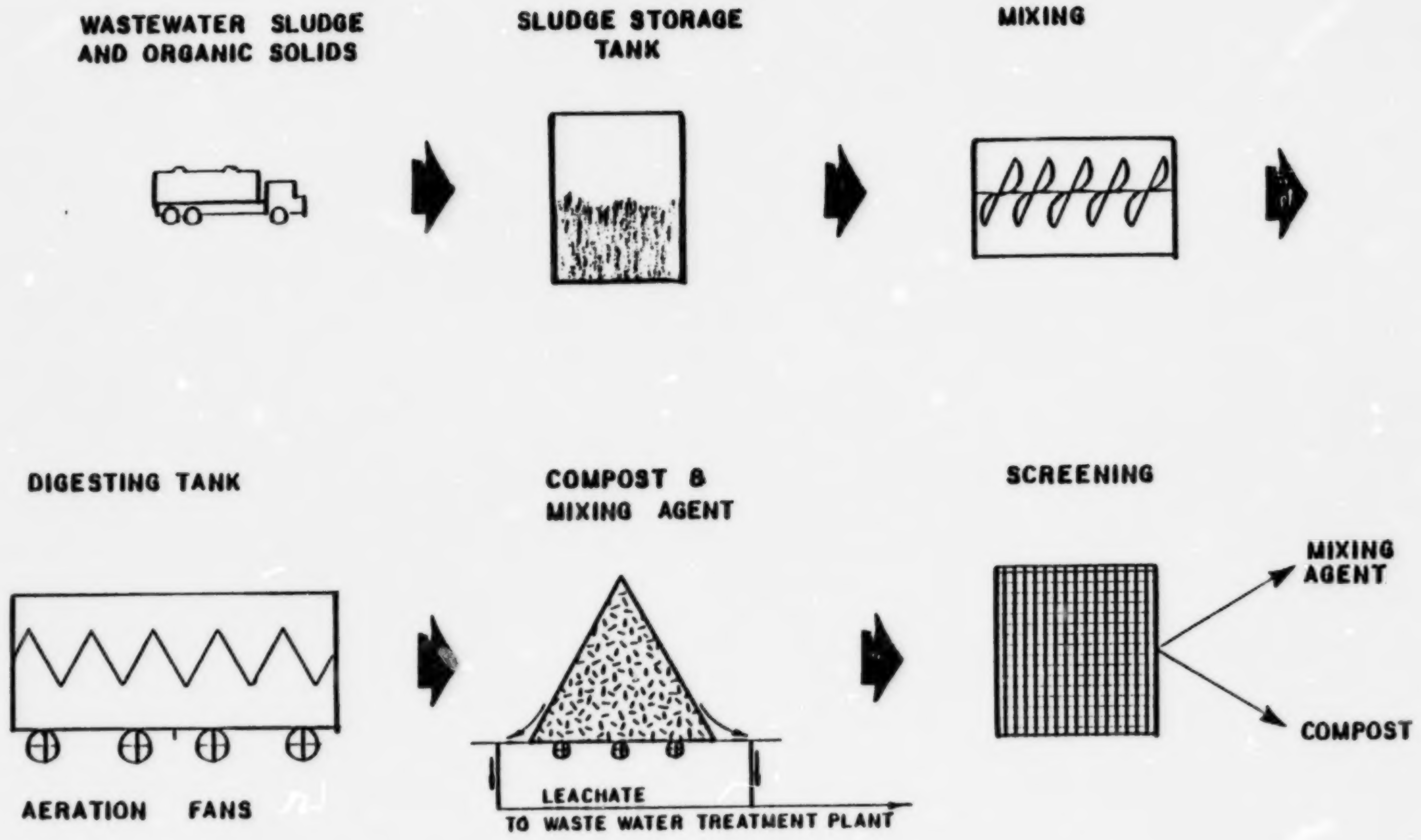
Process Description (Figure 3.2.13)

Composting is a biological process employed to treat wastes with high concentrations of biodegradable organic solids.

Composting achieves the destruction and conversion of waste organics by thermophilic aerobic micro-organisms. A degree of dewatering, deodourizing, and destruction of pathogenic micro-organisms is also accomplished. Composting is a continuous operation which progresses through four stages. Initially, the waste sludge is mixed with wood chips, or other bulking agents, to facilitate aerobic conditions by providing adequate porosity and by lowering the net moisture content (typically 45% to 65% water). The mixture is then allowed to undergo decomposition by thermophilic aerobic micro-organisms. During this stage, heat and air must be supplied, the former by mechanical means and the latter by the micro-organisms themselves. Temperatures of 60°C to 70°C are typical. At the end of this stage, indicated by a drop in temperature, the mixture is permitted to cure, during which further stabilization and deodourizing takes place. The final stage in composting is screening to recover the bulking agent from treated sludge.

Two process types account for most composting experience, viz. static pile composting and windrow composting. Static pile composting uses air mechanically drawn through the pile under laid pipes to maintain aerobic conditions. Exhaust gases are passed through a small pile of cured compost to minimize odours. The active digestion stage typically lasts 21 days when treating biological treatment sludge. A further 30 days are required for curing.

Windrow composting employs front end loaders to periodically turn the 1-1½ m high by 3-4 m wide windrows, turning the windrows normally on a daily basis, provides aerobic conditions and releases excessive heat. Active digestion of biological sludge lasts about six weeks. Curing typically takes a further two weeks.


WASTEWATER SLUDGE AND ORGANIC SOLIDS
SLUDGE STORAGE TANK
MIXING
DIGESTING TANK
AERATION FANS
COMPOST & MIXING AGENT
LEACHATE
TO WASTE WATER TREATMENT PLANT
SCREENING
MIXING AGENT
COMPOST

SOURCE: CONWAY AND ROSS, 1980

FIGURE 3.2.13 : COMPOSTING OPERATION

Waste Inputs

Composting, as a biological treatment process, is only applicable to biodegradable organic wastes. The effectiveness of the process is limited for wastes with excessive moisture, since excessive amounts of bulking agent are required. Carbon to nitrogen ratios of the waste input should be approximately 25 to 1. The pH of wastes should preferably be between 6 and 8. Substances toxic or inhibitory to the thermophilic micro-organisms are not acceptable for composting.

Effluents and Residuals

Significant quantities of leachate can accumulate in composting operations, through percolation and condensation. Leachates are collected in underdrains and must be directed to disposal or treatment. These concentrated wastewaters are typically odouriferous and high in BOD_5.

Residual solids from the process represent, in the case of biological treatment sludge, from 50% to 80% of the original bulk of solids. The compost should be odourless and pathogen-free. Fully cured and air dried compost has a moisture content of 40% to 45%.

Implementation, Reliability

Composting, while not widely employed, has been in use for the treatment of sewage for some years. The major equipment used for composting consists of front-end loaders, conveyors, air blowers, and screens. These items are readily available.

Composting offers a high degree of reliability through its simplicity of operation.

Process Applications

Industrial application of composting has been limited. Most commercial scale industrial use of composting has been with food processing wastes. Pharmaceutical, explosive and various oily wastes also have been successfully composted. Recent work has indicated that some pesticides, chlorinated hydrocarbons and other relatively difficult substances might also be amenable to composting.

Economic Considerations

Capital costs of a 36 dry-tonne per day facility are estimated at $1,600 per kg applied per day, based on 25% solids input. Operating costs are strongly related to amount and type of bulking agent employed. A typical cost would be $0.9/kg dry solids.

Energy Requirements

Composting consumes relatively little external energy. Fuel for front-end loaders and modest electrical energy for blowers and other mechanical equipment.

Resource Recovery Potentials

Cured compost from sewage sludge has been widely employed as a soil conditioner. Other end users for compost have included oil spill sorbent, chicken coop litter and wall board production. Rigorous control of input characteristics is required for any resource recovery.

Environmental Factors

Malodorous sludges can cause aesthetic problems between the time of its arrival on site and its incorporation with bulking agents. Volatilization of certain constituents and formation of aerosols may also restrict downwind land use.

Strong odouriferous leachate requires treatment, generally by biological systems.

The fate of composted solids is governed by the nature of the waste input.

LANDFARMING OR LAND APPLICATION

Process Description (Figure 3.2.14)

Application of municipal liquid sewage sludges on agricultural land has become widely adopted in Ontario in the last few years. Application of liquid industrial sludges to land, through landfarming, has also grown in Ontario, most notably by oil refiners.

Landfarming, also referred to as land application, land spreading, sludge farming, etc., is basically a biological treatment process, in which the large population of micro-organisms present in soil are employed to degrade organic wastes. In addition, the large surface area presented by soil particles and their sorptive characteristics, serves to retain biodegradable organics for microbial assimilation and to attenuate the movement of inorganics and refractory organics.

Land application processes, like other biological treatment systems must present a suitable environment for microbial metabolism. Aerobic conditions are considered necessary to maintain an adequate rate of biodegradation and to permit the assimilation of saturated hydrocarbons which are not significantly affected by anaerobes. Soil pH is maintained at between neutral and slightly alkaline conditions (pH 7 to 9) and inorganic nutrients (especially nitrogen and phosphorus) must be present. Good contact between waste and soil micro-organisms and a suitable moisture content (between 50 and 80% of the soil moisture holding capacity) should be maintained.

Several techniques are employed to apply liquid wastes to land, including:

- Discharge from tank trucks by manifolds or other distributors onto the soil surface.

- Injection below the soil surface from tank trucks through pipes, thus minimizing odours and/or volatilization.

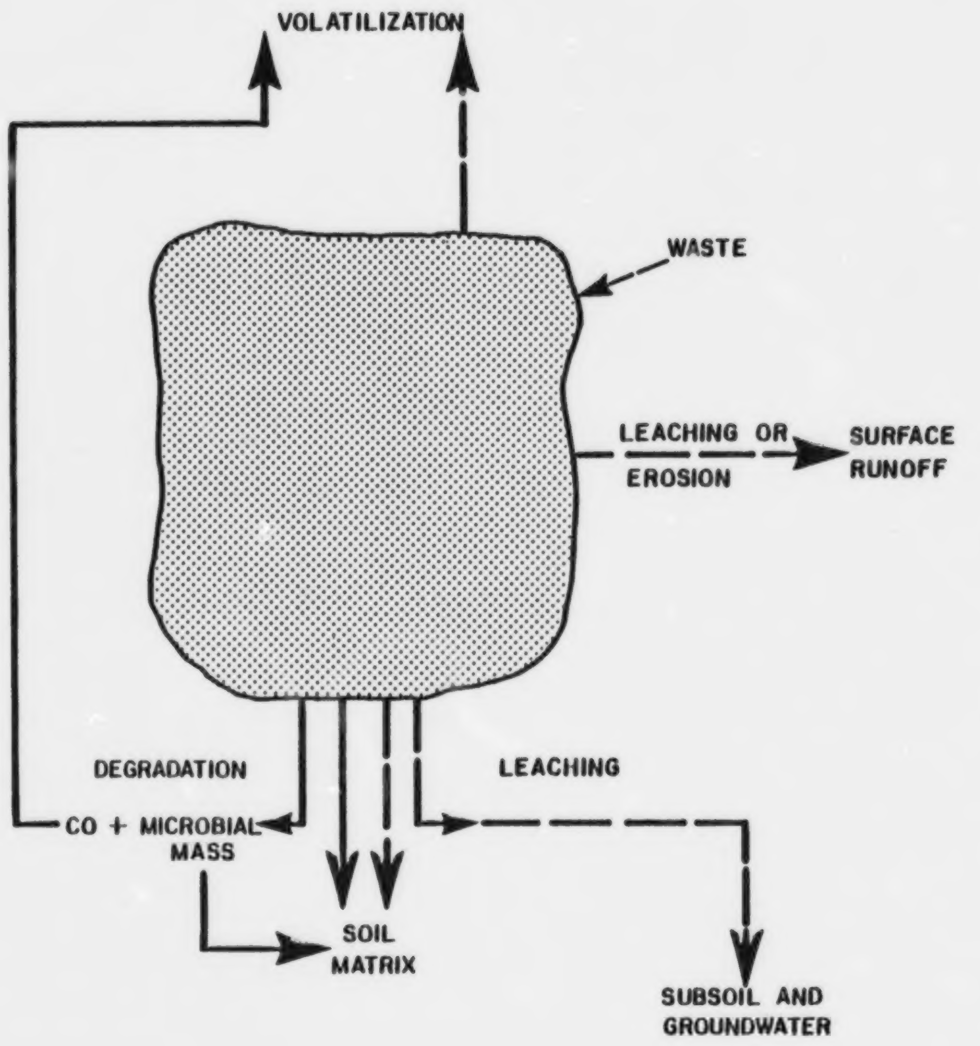

VOLATILIZATION
WASTE
LEACHING OR EROSION
SURFACE RUNOFF
DEGRADATION
LEACHING
CO + MICROBIAL MASS
SOIL MATRIX
SUBSOIL AND GROUNDWATER

FIGURE 3.2.14 LAND FARMING AND FATE OF LANDFARMED WASTES

- Flooded into soil furrows as in ridge and furrow irrigation techniques. Commonly employed on level land in cold climates.

- Spray irrigation, whereby low solids sludges are discharged from nozzles.

After sludge application, the soil and waste are mixed by plowing, discing, or similar methods. If required, fertilizers are also incorporated into the soil.

Soil characteristics are the critical factors in the establishment of land application treatment. Infiltration rates and drainability must be suitable to ensure good aeration. The soil texture should be sufficiently fine to present a large surface area to hold sufficient moisture. In addition, the site should have good soil depth, and have a grade and configuration suitable for the sludge application method to be employed.

Waste Inputs

Landfarming is limited to predominantly organic wastes susceptible to biodegradation. Wastes with concentrations of substances sufficient to be toxic to micro-organisms should not be applied. The wastes applied should be limited to ensure that soils do not accumulate unacceptable levels of toxic inorganics or refractory organics. Leachable and volatile wastes also may not be acceptable.

Effluents and Residuals

In the conventional sense, no residuals or effluents are generated by landfarming of wastes. Ground water may be monitored to ascertain the loss of soluble substances. Surface run-off and volatilization are other possible routes for contaminants. The soil matrix itself represents a residual from the treatment site once it is closed.

Implementation, Reliability

Land application for disposal of wastes is a very simple process once a suitable site has been established. Equipment for waste spreading and soil cultivation are well established.

The key factor in implementing waste treatment by land application is the availability of suitable land.

Process Application

Petroleum refineries have been the source of most of the industrial wastes treated by landfarming. Oily wastes from API separators, slop emulsions, and other sources, and excess biological sludges from refinery wastewater treatment have been disposed by Canadian refiners using this method.

Some wastes from the pharmaceutical and organic chemicals industries have been considered for land application.

Pretreatment of wastes, e.g., heavy metal removal, can greatly increase the potential of land application.

Economic Considerations

Costs of land application of refinery and other industrial wastes vary according to land value and hauling distance. Typical operating costs are quoted at between $10 and $20 per tonne of dry solids. Capital costs have been quoted at $1,600/Kg applied daily.

Energy Requirements

Fuel consumption by equipment used to transport and apply wastes, and to cultivate soil, is the only source of energy consumption.

Resource Recovery Potentials

Little opportunity for resource recovery exists for industrial waste. Marginal or strip mined land may be enhanced by land application, and reclaimed for other productive uses.

Environmental Factors

A properly operated land application site should pose no environmental hazard. Some odours resulting from the spreading of wastes may occur, but should not persist if aerobic conditions are maintained. Strict control of wastes inputs are required to ensure that no air pollution from volatile organics, or ground water contamination by refractory pollutants occurs. Proper design and diking are required to remove the threat of pollution from surface run-off.

Post-closure monitoring of ground water quality and constraints on land use may be required for some sites.

POWDERED ACTIVATED CARBON-ACTIVATED SLUDGE PLANTS

Process Description (Figure 3.2.15)

The use of activated carbon in wastewater treatment has received considerable attention in recent years. Studies have been primarily concerned with the use of columns of granulated activated carbon as tertiary treatment units to remove by adsorption the organic compounds remaining in solution after a biological treatment or physical-chemical treatment. As an alternative, the addition of powdered activated carbon (PAC) to the reactors of plants treating wastewater with activated sludge has been proposed.

In an activated sludge-PAC treatment, powdered activated carbon is added continuously or intermittently directly to the aeration tanks or to the wastewater entering the aeration tanks. The PAC is recycled with the biological sludge solids from the clarifier. Once equilibrium has been reached in the reactor with a constant PAC, wastage of the PAC with the surplus sludge results in an activated carbon solids retention time equal to the biological sludge age. The PAC may be wasted with the sludge or regenerated by oxidization or carbonisation/activation.

The two processes - namely, biological treatment and activated carbon - are complementary since the former oxidizes low molecular weight, soluble polar organic molecules such as carbohydrates which are poorly absorbed by activated carbon, while the latter tends to have greater adsorptive capacity for larger molecules, refractory and slowly biodegradable material. Such refractory material would then be retained much longer within the activated sludge system and allow biological oxidation to take place.

It is also postulated that enhanced renewal of organics using PAC activated sludge systems arises because the activated carbon within an aerated microbial suspension provides a very large number of concentration sites for organic compounds, oxygen and bacteria, hence accelerating biological oxidation. Indirect enhancement of biological oxidation may also result by the activated carbon adsorbing materials that are toxic to the micro-organisms.

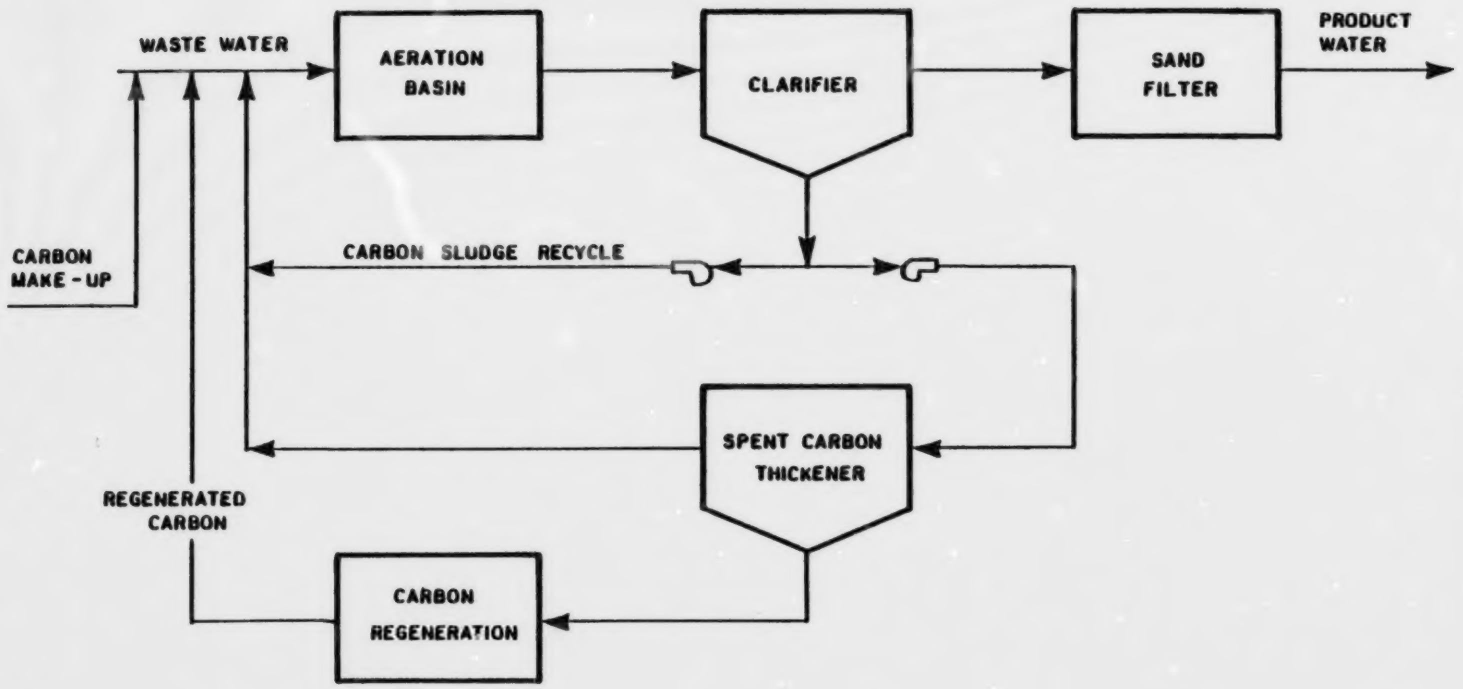

WASTE WATER
AERATION BASIN
CLARIFIER
SAND FILTER
PRODUCT WATER
CARBON MAKE - UP
CARBON SLUDGE RECYCLE
SPENT CARBON THICKENER
REGENERATED CARBON
CARBON REGENERATION

FIGURE 3.2.15 : POWDERED ACTIVATED CARBON ACTIVATED SLUDGE PROCESS

SOURCE: ALEMA AND LUSCEMBE, 1978

Waste Inputs

The application of PAC and activated sludge treatment appears to have a number of attractive features for the treatment of industrial wastewaters for which conventional activated sludge treatment is not suitable because of the presence of toxic or inhibitory organics.

Effluents and Residuals

Liquid effluents from PAC activated sludge processes are likely to be lower in organics and in suspended solids concentration than those from conventional activated sludge plants if high density rapidly settling lignite carbons are used. Sludge from PAC activated-sludge processes, if wasted to anaerobic digesters, is likely to have either no effect or a beneficial effect on digester operation. If regeneration of PAC is carried out by thermal regeneration routes, combustion gases and stripped volatiles would have to be considered. If regeneration is carried out by wet oxidation techniques, solubilisation of heavy metals and release of carbonaceous material and ammonia from sludges would require consideration.

Implementation, Reliability

The optimal dose of PAC would have to be determined on an individual waste basis. PAC activated sludge plants would be expected to have improved reliability over conventional activated sludge plants to shock organic loads, toxic organics and hydraulic overloads.

Process Applications

Petroleum and synfuel process waters and wastewaters have been treated for removal of organics and ammonia by PAC activated sludge systems. Wastes from chemical plants manufacturing dyes and fine chemicals, textile dye and finishing wastes, latex wastes, coke oven discharges, have also been treated successfully.

Economic Considerations

The economics of powdered carbon are difficult to assess without analysing each application separately. The use of carbon does increase operating expense, but reduced total expense may be realized through savings in, for example, defoamers, coagulant aids, reduced sludge handling and vacuum filtration chemicals. The cost of carbon can be justified if it provides treatment such as colour removal or protection from toxic overloads that would otherwise only be attained through the addition of other process units. Most industrial wastes require doses of 20 to 100 mg/L and treatment costs at these levels would be \$0.06 to \$6.26 per m^3. These costs would be reduced if the carbon use warranted regeneration.

Energy

Energy requirements would be only a little more than that required for a conventional activated-sludge plant if regeneration of activated-carbon is not used. Greatly increased energy requirements could be encountered for thermal or wet oxidation regeneration of carbon.

Resource Recovery Potentials

Thermal regeneration combined with the burning or incineration of the biological sludge solids is feasible. Laboratory and small pilot scale studies indicate that the yield of activated carbon is no higher than 40 per cent on a carbon recovery basis and that the product has a high ash content. Thermal regeneration combined with the incineration of the biological sludge solids has also been tried in a multiple hearth furnace, but it is believed that the regenerated PAC requires washing with concentrated hydrochloric acid to reduce build-up of inert solids in the aeration tanks. Wet air oxidation (WAO) at temperatures of approximately 240°C has also been used for regeneration. If the wasted sludge containing PAC is first thickened to about 8% dry solids it is claimed that the subsequent WAO regeneration process is autothermic (i.e., there is an energy credit from oxidation of the biological sludge).

Environmental Factors

Similar environmental factors which apply to conventional activated-sludge would apply to PAC activated-sludge plants. With regeneration of the PAC/sludge residues there would be less of a sludge disposal problem than with conventional activated-sludge plants. Materials handling aspects of powdered carbon require careful consideration since PAC operations can lead to "dirtiness" in the plant surroundings.

ANAEROBIC DIGESTION

Process Description

Anaerobic digestion is a common biological process, installed in many Ontario municipalities as well as in several industries, to treat organic wastes. In addition to reducing complex organics to simpler compounds, anaerobic treatment produces a recoverable fuel gas.

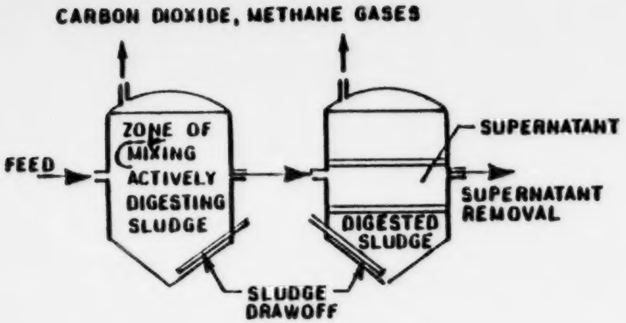
Anaerobic digestion employs an environment devoid of oxygen to promote the growth of mixed cultures of anaerobic and facilative organisms. Three general stages in treatment and related classes of micro-organisms are recognized as comprising anaerobic digestion viz:

- solubilization of solid organic wastes;
- conversion of soluble organics to volatile organic acids, alcohols, carbon dioxide, and hydrogen by acetogenic bacteria;
- conversion of organic acids to methane and carbon dioxide by methanogenic bacteria.

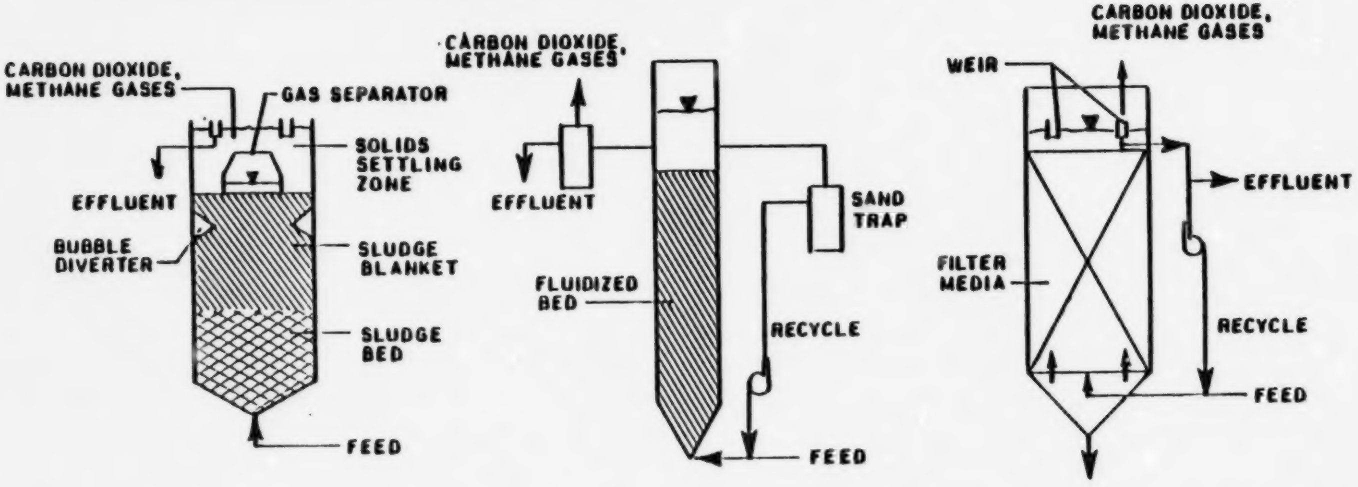
Methanogenic and acetogenic bacteria coexist in a close symbiotic relationship. Methanogenic bacteria are generally considered as a rate limiting factor in the growth of the mixed culture, and thence, most anaerobic digestion processes attempt to optimize conditions for these slow growing microbes. Among these conditions are pH (6.8 - 7.2), alkalinity, temperature (35°C for mesophilic and 55°C for thermophilic operation), and a range of toxic effects to be avoided, e.g., ammonia at less than 3000 mg/L. Many applications employ methane from the process to maintain operating temperature. Several process types have been developed for the anaerobic treatment of wastes, notably:

- Conventional, high rate digestion, generally employing two vessels, one mixed and one quiescent. The liquid and solids (or biomass) retention times are equal. The process is employed with sewage sludge and other high solids organic wastes. Figure 3.2.16a.

SOURCE: HALL ET AL., 1981


CARBON DIOXIDE, METHANE GASES
FEED
ZONE OF MIXING
ACTIVELY DIGESTING SLUDGE
SUPERNATANT
SUPERNATANT REMOVAL
DIGESTED SLUDGE
SLUDGE DRAWOFF

a) CONVENTIONAL HIGH RATE DIGESTER


CARBON DIOXIDE, METHANE GASES
GAS SEPARATOR
SOLIDS SETTLING ZONE
EFFLUENT
BUBBLE DIVERTER
SLUDGE BLANKET
SLUDGE BED
FEED
CARBON DIOXIDE, METHANE GASES
EFFLUENT
SAND TRAP
FLUIDIZED BED
RECYCLE
FEED
CARBON DIOXIDE, METHANE GASES
WEIR
EFFLUENT
FILTER MEDIA
RECYCLE
FEED

b) UPFLOW ANAEROBIC SLUDGE BLANKET TYPE

c) ANAEROBIC FLUIDIZED BED DIGESTER

d) ANAEROBIC FILTER

FIGURE 3.2.16: ANAEROBIC DIGESTER TYPES

(INCLUDING ANAEROBIC PROCESSES)

- Anaerobic contact process, similar to high rate digestion, with solids recycle to increase the biomass to substrate ratio. Requires careful attention to effect sludge separation. Figure 3.2.16b.
- Upflow sludge-blanket digesters employed with high strength carbohydrate wastes which produce a particular granular biological sludge. Figure 3.2.16c.
- Fluidized-bed digesters using hydraulicly suspended inert particles, e.g., sand, to support and retain micro-organisms. Applicable to the treatment of high to low strength predominantly soluble organics. Figure 3.2.16d.
- Anaerobic filter, which supports biological growth on fixed inert media, to treat high stength soluble organic wastes. Figure 3.2.16e.

Waste Inputs

Anaerobic digestion is applicable only to biodegradable organic wastes. The several system types available permit the treatment of a very broad range of waste concentrations and solids contents.

Major fluctuations in organic waste stength are poorly managed by suspended growth systems, but are generally acceptable with attached growth types. Waste inputs should generally be of neutral pH (pH 7). Significant concentrations of various toxic heavy metals (copper 40 mg/L, chromium 110 mg/L, nickel 10 mg/L, etc.) can be inhibitory. High concentrations of common ions can also be inhibiting or toxic (sodium 3500 mg/L, potassium 4500 mg/L, ammonia 300 mg/L, etc.). Pesticides and other toxic organics are also capable of upsetting anaerobic biological processes. Acclimatization over extended periods generally produces a degree of tolerance to both toxic inorganic and toxic organic, while shock loadings can cause system failure.

Effluents and Residuals

Liquid effluent from anaerobic digestion contains low levels of biodegradable organics and soluble organics (including ammonia if nitrate or other reducible nitrogen forms are present). Gases evolved from the process are predominantly CH_4 (60-70%) and carbon dioxide (30-40%) plus lesser amounts of hydrogen, nitrogen or hydrogen sulfide, depending upon feed characteristics. Solids contain insoluble inorganics and organics, including excess biomass. Heavy metals may also be present as insoluble sulfides.

Implementation, Reliability

Conventional high rate anaerobic digesters have been widely employed for domestic sewage sludge and to a lesser extent for manure digestion. The anaerobic contact process and more recently, the upflow sludge blanket digester and the anaerobic filter have been commercialized in Europe. The fluidized bed design, although promising, has not been widely employed.

Required equipment includes tanks, pumps, heat exchangers, gas meters and storage, mixers (for some digester types) and instrumentation. Strict control of pH and temperature are required.

Process Application

Industrial application of anaerobic digestion has been mainly for the treatment of high strength biodegradable wastes from the food processing sector, e.g., meat packing, vegetable processing and distilling industries. Limited experience has also been gained with wastewaters from the organic chemicals industry, pharmaceutical industry, tanneries and cooking plants. Recent work has shown that anaerobic treatment systms may be applicable to a broader range of wastes than had been previously considered.

Economic Considerations

The size and cost of anaerobic digesters is based upon the loading of organic matter. A two-stage high rate digester would have total capital and operating costs of approximately $2,500/kg organics applied daily and $350/ kg organics respectively. Capital and operating costs of anaerobic filters have been reported as $180/kg applied daily and $11.00 per kg of organics respectively.

Energy Requirements

Anaerobic systems treating strong wastes can generate a significant methane credit. Digested sludge free of toxic contaminants can be applied to land as a soil conditioner and fertilizer.

Environmental Factors

The reducing environment of anaerobic digesters leads to the conversion of sulfur compounds to hydrogen sulfide and nitrogeneous material to ammonia. Odoriferous hydrogen sulfide may be evolved with the digester gases and toxic concentrations of ammonia may be present in the liquid effluent. Gas scrubbing and further treatment of liquid effluent may be required. Sludge from anaerobic treatment systems is generally much less than produced by aerobic biological treatment; however, ultimate disposal must be considered.

ENZYME TREATMENT/MUTANT OR ADAPTED MICRO-ORGANISMS

Process Descriptions and Potential Applications

Enzyme Treatment

Many synthetic organic chemicals are refractory and these chemicals, and the compounds involved in their production, are now found in industrial waste waters. Biological systems involving cell-free, enzymatic degradation of some of these refractory organics have been shown to be feasible at the laboratory scale and offer some potential for industrial use. The possibility of obtaining cell-free enzymes from bacterial cultures with detoxifying ability towards various classes of pesticides has been described. For example, a partially purified enzyme preparation from a species of Pseudomonas has been shown to have hydrolytic activity toward phenyl carbamate herbicides. This esterase cleaved the phenylcarbamates forming substituted amines. Similarly, other esterase enzymes have been found which will hydrolyse organophosphates such as malathion, parathion and diazinon, phenoxyacids such as 2,4-D, and acid anilides such as propanil. Cell-free soluble enzymes have also been examined for use in treating wastes from the leather (proteases), wood (celluloses, peroxidases) and paper (celluloses, amylases) industries.

At least one research worker using a parathion hydrolase enzyme covalently immobilized to glass and using continuous flow columns over a period of one month in the laboratory, was able to show, under the industrial conditions found in pesticide production wastewaters or in pesticide container and spray tank rinses, that detoxification of parathion was obtained. The enzyme stability/shelf-life was estimated as 280 days.

Preliminary economic calculations indicate that immobilised pesticide degrading enzyme systems may be able to operate at \$0.108/m^3 wastewater treated (10 ppm parathion) on the basis of enzyme production costs of \$950/kg. The application of soluble or immobilised enzymes may become a new practical method for use in pesticide treatment systems.

Mutant or Adapted Micro-organisms

The philosophy underlying this approach is that biologically refractory organics are persistent because an organism (or organisms) needs several new metabolic steps to channel these new man-made organic materials into existing metabolic pathways and this takes time. There are a number of ways of accelerating this process. The first step usually involves selection and purification of specific bacterial (or fungal) strains by growing them in a culture medium containing the specific refractory organic they have been chosen to digest. Those materials which survive and adapt to growth under these conditions have often undergone some slight genetic change or mutation. These spontaneous natural mutations occur constantly in nature and are part of the "survival package" of micro-organisms. By subjecting cultures to high intensity radiation or chemical mutagens, these random natural processes can be accelerated providing a broad selection of mutants from which further selection can take place. The process can then be continued with the most successful mutants grown in progressively higher organic contaminant concentrations. The end result is a micro-organism with a greatly enhanced ability to survive and multiply in a specific waste at concentrations which would have been toxic to the parent organism. However, mutant strains adapted to a specific waste will not compete effectively in more normal environments and, if cultured in the absence of the specific organic compound, a population of mutants will either revert to a less well adapted state or die off.

Adapted or mutant strains of micro-organisms or mixtures of micro-organisms are available commercially (usually as a freeze-dried product) for degrading of petrochemical wastes, petroleum refinery wastes and oily sludges, textile and dyehouse wastes, cyanides and food processing wastes. Such cultures could be very useful in rapidly establishing a biological waste treatment system for the degradation of defined hazardous or toxic organic wastes.

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3.3 PHYSICAL AND CHEMICAL TREATMENT

INTRODUCTION

Physical and chemical treatment processes offer wide application to waste management in the Province of Ontario. Physical/chemical processes are generally applicable to spent acids, heavy metal solutions, liquids, sludges, emulsions, etc. and are in wide use for industrial waste treatment and pretreatment. It should be noted that many of these processes are used in industrial applications for waste recovery.

This section of the document presents a discussion of the physical and chemical treatment processes that are applicable to the treatment of hazardous wastes generated within the Province of Ontario. Physical treatment technologies generally include processes which separate components of a waste stream or change the physical form of the waste without altering the chemical structure of the constituent materials. Chemical treatment technologies alter the chemical structure of the constituents to produce a waste residue which is less hazardous or no longer hazardous in characteristics.

Physical and chemical treatment processes may be classified into several general categories: [1]

- **Phase Separation:** physical processes designed to separate multi-phase waste streams such as slurries or suspensions, sludges and emulsions prior to detoxification or recovery operations (e.g., filtration, centrifugation, etc.)
- **Component Separation:** physical processes designed to segregate ionic or molecular species from multi-component waste streams without chemical reactions (e.g., ion exchange, adsorption, stripping, etc.)
- **Chemical Transformation:** treatment processes that involve chemical reactions to detoxify waste streams, reduce waste volumes, or recover resources (e.g., neutralization, precipitation, oxidization/reduction, etc.)

Prior to component separation or chemical transformation steps, a phase separation process may be required in waste streams, such as sludges, slurries, and emulsions. Phase separation often permits a significant volume reduction, particularly if one of the phases contains a highly concentrated component. In addition to volume reduction, phase separation technologies allow sequential processing steps to be accomplished more readily. Phase separation processes are usually mechanical, inexpensive and simple, and can be applied to a broad spectrum of wastes and waste components.

Many physical processes act to segregate ionic or molecular species from multicomponent waste streams and do not require chemical reactions to be effective. The majority of component separation processes act only on aqueous solutions. A great deal of experience has been gained from their use in the water treatment field.

In addition to decreasing or destroying the hazardous constituents in waste streams, physical/chemical treatment methods may also be utilized for volume reduction and/or resource recovery.

PHYSICAL/CHEMICAL TREATMENT TECHNOLOGIES

Of the available physical treatment technologies, 11 processes are discussed and evaluated for their applicability to hazardous wastes generated in the Province of Ontario. Each physical treatment process is listed and briefly discussed below, and detailed descriptions follow within this section of the report.[1]

- **Carbon Adsorption:** a process particularly suited for the removal of refractory organics, toxic substances and colour. Dissolved materials are attracted to the surface of the carbon primarily by Van der Waals forces. Spent carbon may be regenerated thermally or by the use of a suitable solvent. During regeneration, a fraction of the carbon is lost which must be replaced.

- **Resin adsorption:** is similar to carbon adsorption and is used mainly for the removal of dissolved organics from aqueous solutions. Resin adsorbents are regenerated with appropriate solvents.

- **Centrifugation:** a process for separating solid/liquid or liquid/liquid suspensions of different specific gravity utilizing centrifugal force. The rotational or centrifugal force enhances separation by applying significantly greater force than gravity in sedimentation. Centrifugation is most often applied to sludge dewatering operations.

- **Electrodialysis:** a later development of dialysis, this process is used to separate electrolytes through the use of electrical currents. The current causes ions to diffuse through a dialysis membrane. Electrodialysis processes are effective for extracting acids and metal salts from solutions.

- **Filtration:** a process for separating liquids and solids using various types of porous media. The suspended particles are removed by forcing the liquid through the filter medium. There are many types of filters (e.g., pressure, gravity, etc.) designed to achieve various levels of separation.

- **Reverse Osmosis:** a membrane separation process for liquid waste streams that applies a high external pressure (2000 - 10000 kPa) to one side of the membrane so that the solvent will flow in the opposite direction, i.e., opposing the osmotic pressure gradient.

- **Ultrafiltration:** a process similar to reverse osmosis, but operates at much reduced pressures (70 - 700 kPa) and generally applicable for the separation of suspended impurities (e.g., particulate oil and grease, etc.). Certain chemical compounds with high molecular weight are also retained by the membrane. However, dissolved components of lower molecular weight pass through the membrane with the bulk liquid, while the higher molecular weight components are more concentrated through the loss of solvent.

- **Stripping:** a process used primarily for the removal of volatile organics (e.g., organic solvents) and strippable inorganics (e.g., ammonia). Packed and spray towers or ponds are generally utilized in stripping process design. The process utilizes continuous operation in a packed tower or conventional fractionating distillation column and can use either air or steam for stripping.

Of the available chemical treatment technologies, seven are presented in this section and are evaluated for their application to hazardous waste management in the Province of Ontario. Each chemical treatment process is listed and briefly discussed below:

- **Chemical Dehalogenation:** a process for stripping chlorine from chlorinated compounds such as PCBs. One of the processes uses a metallic sodium reagent to break the chlorine-carbon bond.

- **Hydrolysis:** a process predominantly used to treat organic matter, usually through double decompositon reactions with water. The process takes place at high temperatures and may require the presence of a catalyst.

- **Ion Exchange:** a process for removing inorganic ions from aqueous solutions. It involves the exchange of ions for the inorganics to be removed as the solution is passed over a resin bed. Once the resin capacity is utilized, it can be regenerated with appropriate regenerant solution (e.g., caustic, brine, etc.).

- **Neutralization:** a common process for reducing the alkalinity or acidity of a waste stream by mixing acids and bases to produce a solution with the desired pH value.

- **Oxidation:** a process for treating hazardous waste streams utilizing redox reactions in which the valence of the chemical species is increased. Electrons are transferred, and the oxidation state of the oxidized species is increased.

- **Reduction:** a process for the treatment of hazardous waste streams utilizing redox reactions in which the valance of the chemical species is decreased. Chemical bonds are broken, electrons are transferred, and the oxidation state of the reduced species is decreased.

- **Precipitation:** a process for removing soluble compounds in a liquid waste stream through the alteration of the chemical solubility equilibrium. A specific chemical is added to cause the formation of insoluble precipitates which can be readily separated utilizing physical separation techniques (e.g., clarification).

- **Solvent Extraction:** a process which separates pollutants from effluents by employing selective solvents having a high affinity for the chemicals to be removed.

- **Electrolytic Processes:** are electrochemical methods which can be used to destroy cyanides plate out metals or convert trivalent chromium to the hexaualent form.

Additional physical and chemical treatment processes may be available for application to waste management; however, many are in the experimental stage with little developmental work and no proven history or application, or are integral parts of other treatment technologies. An expanded discussion of these technologies has not been included within this study because they have not been demonstrated as effective treatment technologies. Some of these additional treatment technologies that are not included within this text include:

- Electron Beam
- Electrophoresis
- Freeze Drying
- Freeze Crystallization
- Catalysis
- Photolysis
- Emulsion Breaking
- Dialysis
- High Gradient Magnetic Separation

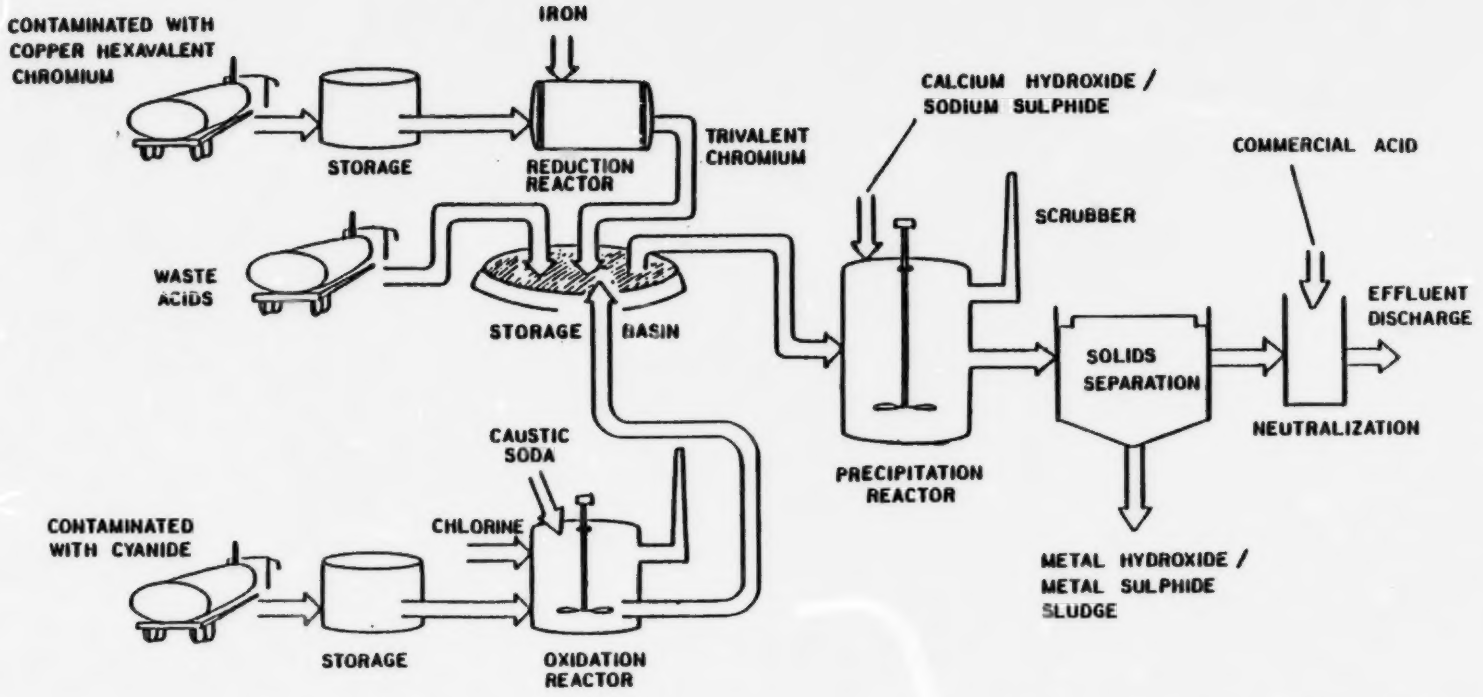
APPLICABILITY OF TECHNOLOGY [2]

Application of a physical or chemical treatment process to a specific hazardous waste stream is dependent upon technology status, process economics, and environmental considerations. The proven effectiveness as well as the reliability of the technology are important in selecting a specific treatment technology. Economic decisions must be based upon the capital, operating, and maintenance costs associated with the application of a given technology. Environmental questions must also be addressed, such as the degree of treatment, destruction, or volume reduction achieved, the impacts upon air, water and land use, and the potential public health effects.

Physical/chemical processes are rarely applied in a single operation, but rather a few individual treatment technologies are incorporated together to provide adequate waste management. A common example of combined chemical treatment operations is shown as Figure 3.3.1. This figure presents a schematic of a chemical treatment operation for aqueous solutions containing heavy metals (copper and hexavalent chromium), dilute inorganic acids, concentrated acids, and cyanide. It depicts the successful integration of various unit operations (e.g., oxidation/reduction, precipitation, clarification, etc.) for treating varied waste streams.

All physical/chemical treatment processes generate an effluent and a residual sludge or concentrated waste. The treated effluent (the desired product of the treatment operation) may be discharged to municipal sewers or local streams, spray irrigated for disposal, or used as makeup water in scrubbers or cooling towers. The residual sludges and the concentrated liquid wastes may require further treatment (e.g., incineration, solidification/stabilization) prior to ultimate disposal in a secure landfill, underground mine, or salt deposit storage.

The feasibility of applying a specific physical/chemical treatment technology is of major importance to waste management in the Province of Ontario. Each of the treatment technologies is evaluated in detail within a two-page


CONTAMINATED WITH
COPPER HEXAVALENT
CHROMIUM
STORAGE
IRON
REDUCTION
REACTOR
TRIVALENT
CHROMIUM
WASTE
ACIDS
STORAGE
BASIN
CALCIUM HYDROXIDE /
SODIUM SULPHIDE
SCRUBBER
COMMERCIAL ACID
EFFLUENT
DISCHARGE
SOLIDS
SEPARATION
NEUTRALIZATION
PRECIPITATION
REACTOR
METAL HYDROXIDE /
METAL SULPHIDE
SLUDGE
CAUSTIC
SODA
CHLORINE
CONTAMINATED
WITH CYANIDE
STORAGE
OXIDATION
REACTOR

SOURCE: OFFICE OF APPROPRIATE TECHNOLOGY/
STATE OF CALIFORNIA, 1981

FIGURE 3.3.1 :COMBINED CHEMICAL TREATMENT OPERATION

CHEMICAL OXIDATION / REDUCTION, PRECIPITATION & NEUTRALIZATION description. Included within this evaluation are the factors of implementability, reliability, process applications, appropriate waste inputs (categorized by corresponding UCD classification numbers), economics, energy requirements, resource recovery potentials, environmental factors and institutional considerations.

CARBON ADSORPTION

Process Description (Figure 3.3.2) [1]

Many solids are capable of attracting to their surface soluble and gaseous chemicals from a solution or mixture. This phenomenon is called adsorption. The adsorption process is very effective in accumulating or removing surface active chemicals (e.g., detergents) due to interfacial accumulation. As a result, one of the desirable properties of an adsorbent is to have a large surface area per unit volume. Activated carbon is a porous material having a high capacity for adsorbing soluble organics from wastewater. Activated carbon has been the subject of several full-scale and pilot-scale investigations for reducing air and water pollution. Adsorption systems are widely used in industry to remove gases and vapours that can produce human irritants, obnoxious odours, hazardous concentrations and undesirable products and byproducts. In general, the process works best with chemicals that have a low water solubility, high molecular weight, low polarity, and low degree of ionization.

The physical adsorption is reversible and, therefore, adsorbed materials can be later removed utilizing thermal or solvent regeneration techniques. Virgin activated carbon is available both in granular (8 to 40 mesh) and powdered form (approximately 10 micron size particles). Granular activated carbon is more widely used than powdered activated carbon because it is easier to regenerate.

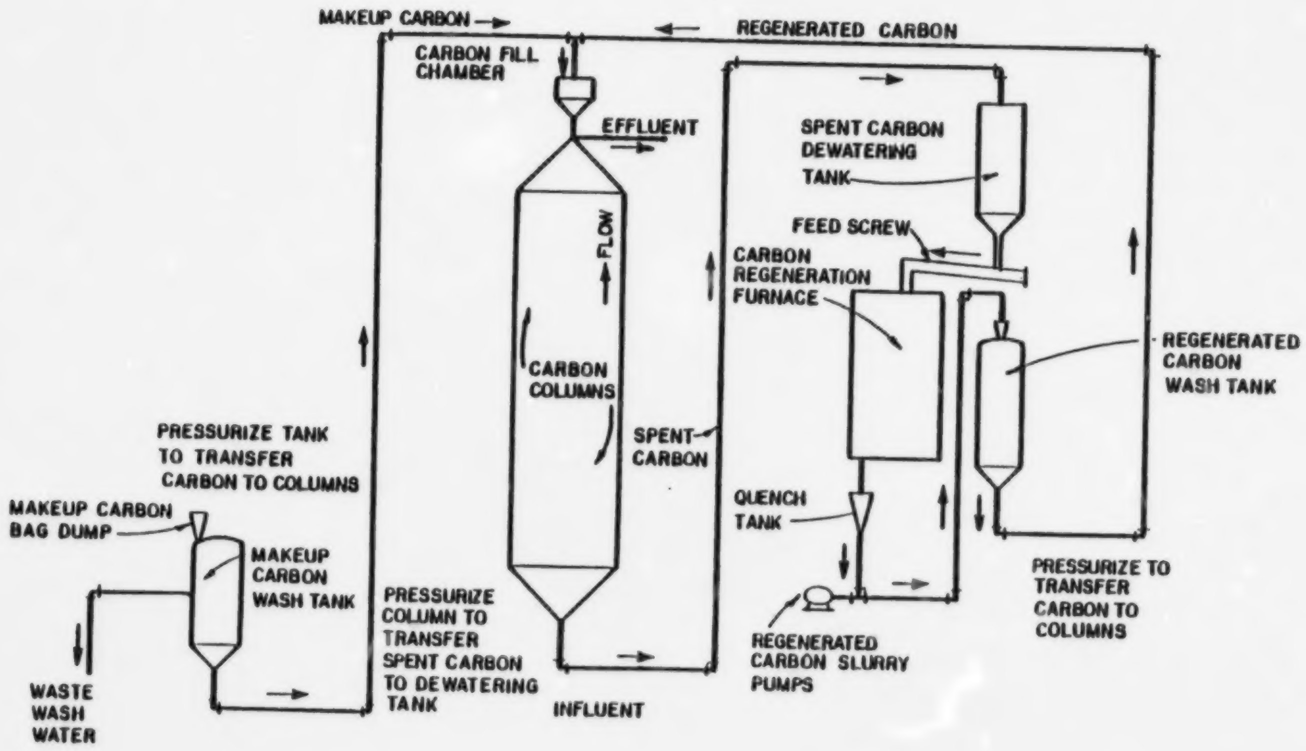

MAKEUP CARBON
REGENERATED CARBON
CARBON FILL CHAMBER
EFFLUENT
SPENT CARBON DEWATERING TANK
FEED SCREW
CARBON REGENERATION FURNACE
FLOW
CARBON COLUMNS
REGENERATED CARBON WASH TANK
PRESSURIZE TANK TO TRANSFER CARBON TO COLUMNS
SPENT CARBON
MAKEUP CARBON BAG DUMP
QUENCH TANK
MAKEUP CARBON WASH TANK
PRESSURIZE COLUMN TO TRANSFER SPENT CARBON TO DEWATERING TANK
PRESSURIZE TO TRANSFER CARBON TO COLUMNS
REGENERATED CARBON SLURRY PUMPS
WASTE WASH WATER
INFLUENT

FIGURE 3.3.2: ACTIVATED CARBON ADSORPTION WITH REGENERATION

SOURCE: A.D. LITTLE, 1977

Waste Inputs [1]

Although activated carbon adsorption is applied chiefly for the removal of organic species, it is also used for the removal of mercury from chlor-alkali waste streams and for the treatment of plating wastes (e.g., for chromium removal). Using the UCD classification, it is appropriate for the treatment of the following wastes: 211-217; 221-224; 225-228; 241-243; 251.

Effluent and Residuals [1]

Carbon adsorption processes produce a treated effluent, a backwash effluent, and a spent carbon residual. The treated effluent generally is suitable for surface water discharge but may require additional treatment to remove remaining solutes. Other water streams (backwash, carbon wash, and transport waters) are recycled or sent to settling basins. When spent carbon is not regenerated, it must be discarded.

Implementation, Reliability [1]

Carbon adsorption represents a proven technology for the removal of most organic and some inorganic species from single-phase fluid waste streams. Influent suspended solids concentrations should be less than 50 ppm in order to minimize fouling and plugging of pore space in the carbon column. There are no technical limits on the flow rate of the feed stream as adsorbers of varying sizes can be arranged in series and/or parellel operation.

Process Applications [1]

There are several hundred full-scale carbon adsorption systems currently in use in North America and overseas for industrial and municipal wastewater treatment. Leading industrial users of activated carbon treatment include petroleum refineries, pulp and paper mills, textile plants, and chemical manufacturing facilities.

Development of new methods of regeneration, particularly ones that allow recovery of the adsorbate, could greatly expand potential applications of the process.

Economic Factors [1]

Capital costs for a 400m^3/day facility would be in the range of $1,000,000 to $5,000,000. Total operating costs would be in the range of $1-5m^3. For aqueous wastes containing less than one percent (10,000 mg/L) adsorbable organics, activated carbon adsorption is a viable and proven technology. For higher concentrations, the frequent regeneration required and the requirement for virgin makeup carbon will significantly increase the operating costs.

Energy Requirements [1]

Energy requirements include electricity for pumps, utilities, and fuel for the regeneration furnace. Energy costs may be around 25% (or higher) of the annual operating costs where concentrated waste streams are being treated and the carbon is thermally regenerated. Energy may constitute no more than 5% of annual operating costs if regeneration is accomplished by non-thermal means.

Resource Recovery Potential

There are possibilities for material recovery of organics and inorganics in a few cases (e.g., phenols, acetic acid, ethylene diamine, and Cr). The carbon of course can be regenerated and reused.

Environmental Factors [1]

The carbon treated effluents are generally of high quality. The adsorption process does not chemically alter the toxic chemical species present in wastes; however, the process retains and accumulates these chemicals so that the treated effluent is generally non-hazardous. There are no serious environmental impacts from carbon systems using thermal reactivation since the only output streams are:

1. a purified liquid (e.g., water), and

2. furnace gases which have been through an afterburner and a scrubber, and in some cases, a dust filter.

When the carbon is chemically regenerated, the major output streams consist of:

1. the purified liquid
2. spent regenerant
3. used carbon.

Chemical regeneration, however, is not very effective for carbon regeneration. For example, the phenol recovery unit at Dow Chemical (Midland, Michigan) has required replacement of carbon beds about once every two years. This waste carbon, which requires ultimate disposal, may constitute minor environmental concern.

Institutional Considerations

Carbon adsorption processes pose no unusual insitutional problems; however, there are requirements for ultimate disposal of waste residues and there may be requirements for treatment of the liquid effluent prior to discharge.

RESIN ADSORPTION

Process Description (Figure 3.3.3) 1

Synthetic polymeric adsorbents are hard, insoluble spheres of high surface, porous polymer. They are available in a number of mesh sizes and in a variety of polarities and surface characteristics.

Removal of pollutants by adsorbent resins is similar to the mechanism operating with activated carbon. Spent resins are chemically regenerated using caustic or organic solvents. In many cases, methanol has proven to be a good eluant, and also has the advantage of being comparatively inexpensive.

Waste treatment by resin adsorption involves two basic steps:

1. contacting the liquid waste stream with the resins and allowing the resins to adsorb the solutes from the solution; and
2. subsequently regenerating the resins by removing the adsorbed chemicals, often effected by simple washing with the appropriate solvent.

Waste Inputs 1

The feed stream must be a single liquid phase, and in most cases will be an aqueous solution. Suspended solids should be less than 50 ppm, control of influent pH is necessary, process temperatures should be kept low, and strong chemicals that would react with the resins must be removed prior to treatment with the resins. Appropriate for treatment of the following wastes (by UCD classification): 211-217; 221-228; 241-243; 251.

Effluent and Residuals 1

Resin adsorption processes produce a treated effluent from which a significant portion of the organic solute has been removed and is suitable for direct discharge. Adsorbent regeneration produces an effluent containing the solutes retained by the resin. Spent regenerant solution requires proper treatment or disposal. If the regenerant used is an organic solvent, it may be largely recovered by distillation and the residue burned.

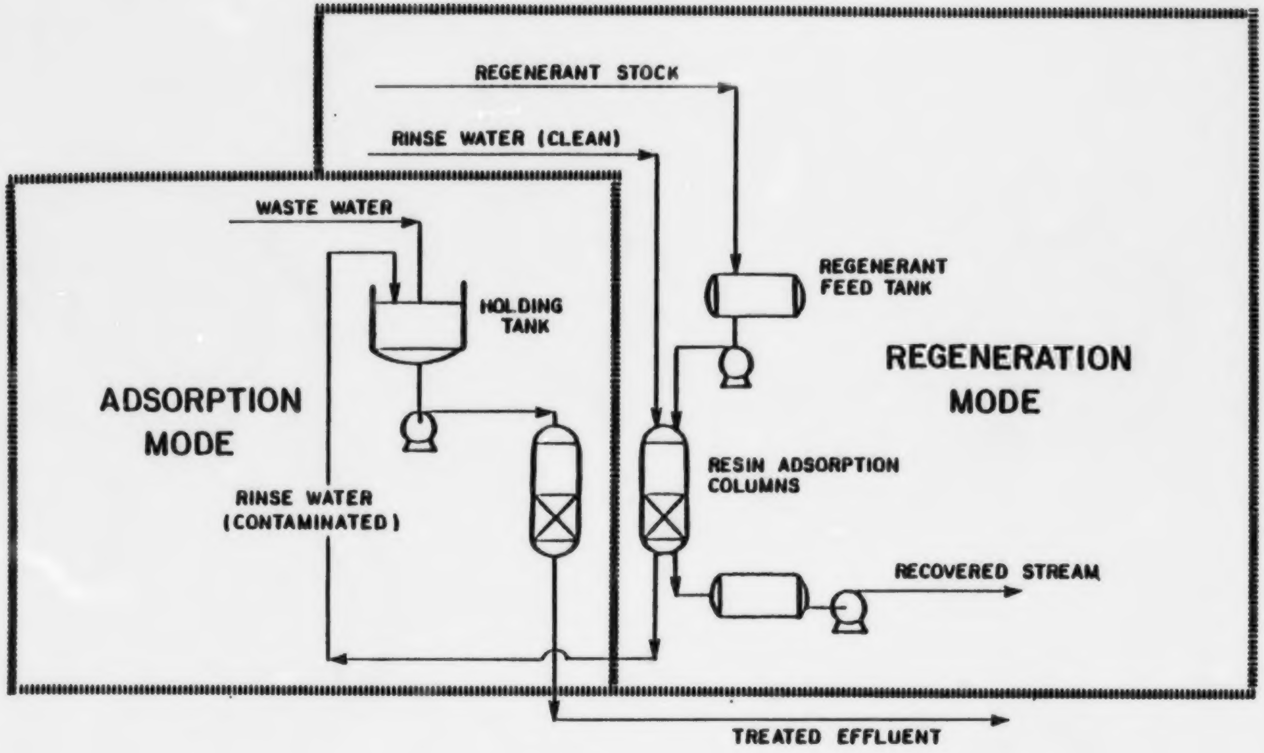

REGENERANT STOCK
RINSE WATER (CLEAN)
WASTE WATER
REGENERANT FEED TANK
HOLDING TANK
REGENERATION MODE
ADSORPTION MODE
RESIN ADSORPTION COLUMNS
RINSE WATER (CONTAMINATED)
RECOVERED STREAM
TREATED EFFLUENT

FIGURE 3.3.3 : SCHEMATIC FLOW DIAGRAM – SYNTHETIC RESIN ADSORPTION

SOURCE: A.D. LITTLE, 1976

Implementation, Reliability [1]

Resin adsorption processes requires similar process equipment and process control instrumentation to that used in the activated carbon adsorption process. Therefore, the process is readily implementable. Since resin adsorption is a relatively new technology, selecting suitable resins to achieve the desired degree of treatment for any particular wastewater should be made through pilot plant studies.

Process Applications [1]

Current industrial waste treatment applications include: phenol recovery; colour removal from textile mill effluents; and fat removal from aqueous waste streams. The phenol concentration can be as high as 8% by weight in the feed.

Proposed waste treatment applications (near-term) include removal of toxic chemicals from munitions facilities' effluents; removal of pesticides from aqueous streams; removal of carcinogens from laboratory waste waters; removal of phenolics; and removal of chlorinated hydrocarbons.

Resin adsorption is particularly attractive for removing organics from aqueous waste streams when material recovery is desirable, and when the waste stream contains high levels of dissolved inorganic salts. Applications into waste management will continue to expand.

Economic Factors [1]

Capital costs are moderately high since resins costs are high. Operating costs may be below $\$0.25/m^3$ in some applications, but can be substantially higher when concentrated waste streams are treated and the solute is recovered. Credit for recovered solute can allow a system to partially offset operating costs.

Resource Recovery Potential

The potential for material recovery is greater with resin adsorption than with carbon adsorption processes as long as the solutes are present in high enough concentrations. When solute recovery is not feasible, the solvent regenerant waste may be suitable for use as fuel supplement in existing boilers or can be incinerated in a liquid waste incinerator, thereby generating little or no residue requiring ultimate disposal.

Energy Requirements [1]

Energy requirements are minor when fractional distillation is not utilized to recover and recycle the regenerant solvent. In systems where distillation is not utilized, energy requirements may account for as little as 5% of the annual operating costs. When both solute and solvent are recovered, steam requirements for distillation will be significant.

Environmental Factors [1]

The disposal of used regenerant solutions or extracted solutes pose the only environmental concern when they are not recycled or incinerated on-site. Minor impacts may arise from the discharge of rinse waters, but in most situations these can be treated with other (non-hazardous) process wastes.

Institutional Considerations

There are no unusual institutional considerations, but resin adsorption processes require proper disposal of waste residues.

CENTRIFUGATION

Process Description (Figure 3.3.4) [1]

Centrifugation is a physical process whereby the components of a fluid mixture are separated mechanically by the application of centrifugal force, applied by rapidly rotating the mass of fluid within the confines of a rigid vessel. Centrifugal forces acting on the revolving mass of fluid cause the solids suspended in the fluid to migrate outward to the inner walls of the vessel where they can be separated. The particles are removed as a liquid/solid mixture significantly more concentrated than the original liquid.

With centrifugation, the rotational force is analogous to the gravitational force in the sedimentation process. Centrifugal forces, however, are equal to several thousand times the force of gravity in sedimentation, thereby greatly enhancing the separation process.

Centrifugation is a well-developed liquid/solid separation process which is used in a variety of full-scale applications for material processing and waste treatment. In treating hazardous wastes, centrifugation can be most advantageously used to increase the efficiency of phase separation between two fluids or liquid/solid suspensions having different specific gravities. As a result, the process provides a viable alternative when separation of hazardous and non-hazardous compounds and volume reduction are desired.

The many applications have resulted in a large number of equipment configurations. Fundamentally, centrifuges fall into two categories: sedimentation centrifuges and filtering centrifuges. In the sedimentation centrifuge, the solids accumulate in a layer or "cake" on the inner wall of the rotating vessel. In the filtering centrifuge, a cake of granular solids is deposited on a filter medium held in a rotating basket.

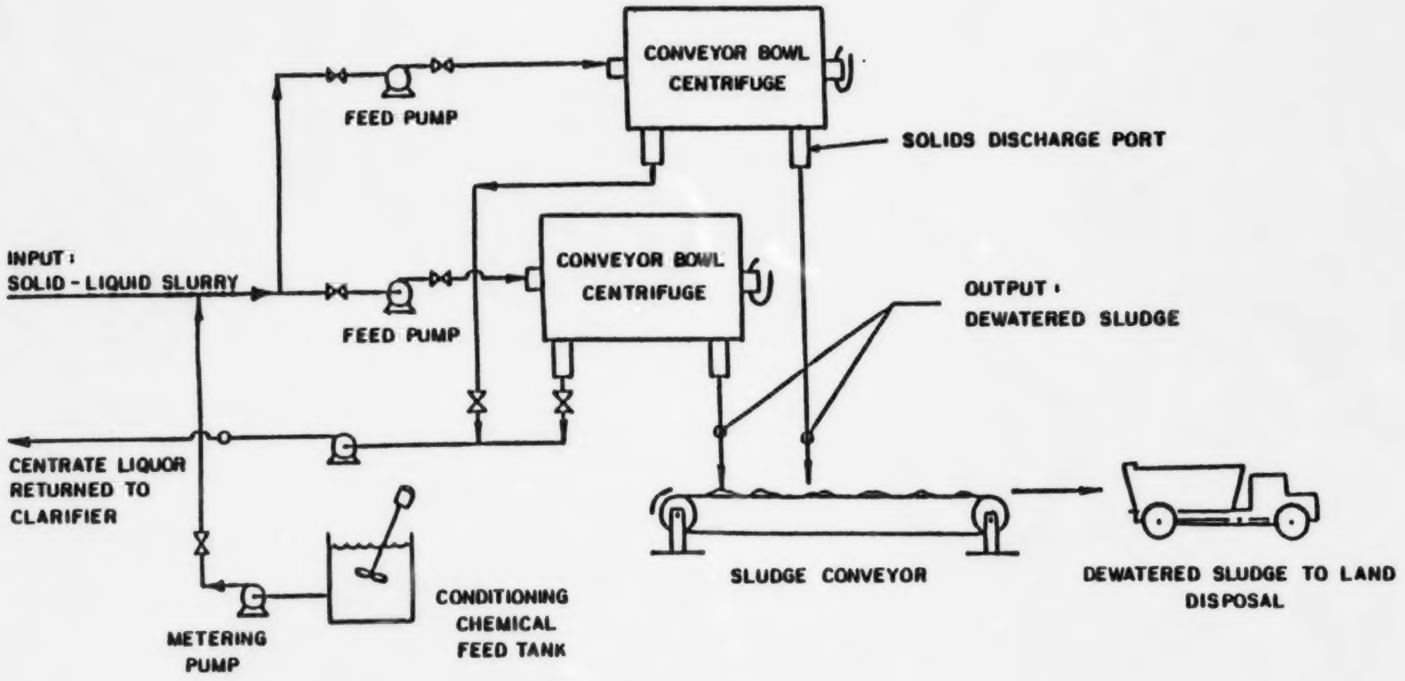

CONVEYOR BOWL CENTRIFUGE
FEED PUMP
SOLIDS DISCHARGE PORT
INPUT:
SOLID - LIQUID SLURRY
CONVEYOR BOWL CENTRIFUGE
OUTPUT:
DEWATERED SLUDGE
FEED PUMP
CENTRATE LIQUOR RETURNED TO CLARIFIER
SLUDGE CONVEYOR
DEWATERED SLUDGE TO LAND DISPOSAL
CONDITIONING CHEMICAL FEED TANK
METERING PUMP

FIGURE 3.3.4 : TYPICAL PROCESS FLOW SCHEMATIC ; SOLID - LIQUID SEPARATION UTILIZING CENTRIFUGES

SOURCE: A.D. LITTLE, 1977

Waste Inputs [1]

The centrifugation process is suitable for separating solid/liquid or liquid/liquid suspensions having different specific gravities. Depending upon the efficiency of separation, the aqueous effluent may still contain waste residues requiring further treatment and disposal. Appropriate for treatment of the following wastes (by UCD classification): 165; 167; 251; 261-262; 282-286; 228-289; 417; 431; 433; 441-447; 454-455.

Effluent and Residuals [1]

Centrifugation produces an aqueous effluent and a waste residue. The process may also generate a sludge or sludge cake of relatively high solids concentration which requires ultimate disposal through landfilling or incineration.

Implementation, Reliability [1]

Centrifugation is a proven technology for dewatering waste sludges. It is generally technically and economically competitive with other dewatering processes including vacuum filtration or the filter press and should be considered as a viable alternative for processing hazardous waste sludges and slurries. Equipment is commercially available in a large variety of sizes and configurations.

Process Application [1]

Currently, the main application for centrifuges is probably the dewatering of waste sludges. Some other common applications include the following: separating oil and water mixtures; clarification of viscous gums and resins; classification and removal of oversize particles and unground pigments from lacquers or enamels; clarification of essential oils, extracts and food products such as homogenized milk and fruit juices; separation of micro-organisms from fermentation broths, recovery of finely divided metal such as silver from film scrap and platinum from spent catalyst; separation of acid sludges from the acid treatment of petroleum; recovery of crystalline solids from brine; dewatering of fibrous solids such as paper pulp and chemical fibers; dewatering and removal of starch from potato fibers, etc.

Economic Factors[1]

In most applications, centrifugation costs range from $25-50/ton.

Energy Requirements[1]

Power requirements for centrifugation are typically 60 - 240kW per m^3 per minute of inlet waste feed. Power consumption is equal to or slightly greater than for other sludge dewatering processes.

Resource Recovery Potential

Centrifugation offers little or no potential for resource recovery when handling a mixture of waste streams or slurries. However, when centrifugation is used to separate an oil-water mixture, the separated oil can be reused in the process or the fuel value can be recovered by using it as a fuel supplement.

Environmental Factors[1]

Centrifugation represents an excellent process to dewater sludges and reduce necessary disposal volumes. The process creates no additional environmental hazards.

Institutional Considerations

Centrifugation poses no unusual institutional considerations; however, ultimate disposal of the waste residues and wastewater treatment of the effluents must be considered.

DEHALOGENATION

Process Description (Figure 3.3.5) [2,3]

Chlorinated organics are among the most toxic compounds discharged by industries and the high toxicity of these substances is largely due to the presence of the chlorine atoms in the molecular structure. One of the novel methods developed to cope with such wastes is dehalogenation which strips the chlorine atoms from the compounds producing a less or non-hazardous residue.

Chemical dehalogenation employs a highly reactive reagent (e.g., sodium or sodium naphthalide) to accomplish the chlorine stripping. This technique is an example of a tailored chemical reaction designed to reduce the degree of hazard associated with chlorinated hydrocarbons.

Waste Inputs [3]

Chlorinated hydrocarbons such as polychlorinated biphenyls (PCBs), tetrachloroethylene, chlorobenzene, dichlorophenols, vinyl tetrachloride, and an assortment of pesticides such as aldrin, heptachlor, 2,4-D, 2,4,5-T are applicable wastes for chemical dehalogenation. Appropriate for treatment of the following wastes (by UCD classification): 211-213; 221-222; 226; 228, 241-242.

Effluent and Residuals

The effluent stream from chemical dehalogenation processes contains compounds of reduced halogen content which are relatively non-hazardous.

Implementation, Reliability [3]

Chemical dehalogenation has yet to be demonstrated in widespread, full-scale applications. However, according to pilot plant studies with PCB-contaminated oils, significant reductions in PCB concentration can be achieved by this method. Most of the chemical dehalogenation processes currently under development are compact and can be mounted on trailers and readily transported to the desired site to destroy small or large quantities of

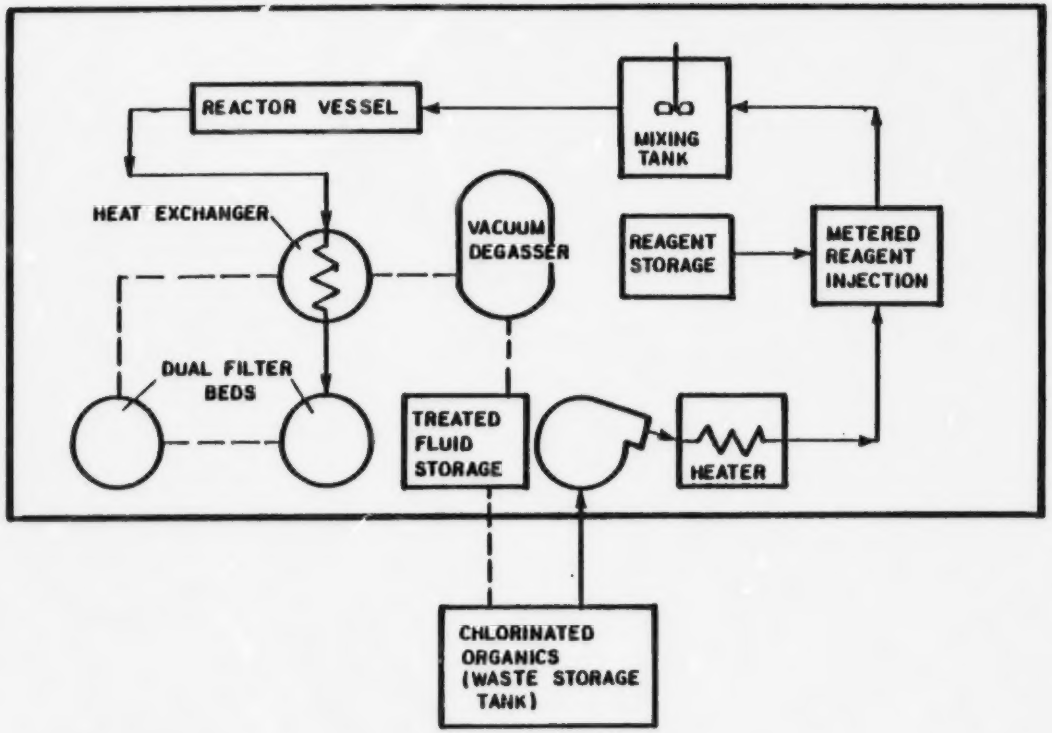

REACTOR VESSEL
MIXING TANK
HEAT EXCHANGER
VACUUM DEGASSER
REAGENT STORAGE
METERED REAGENT INJECTION
DUAL FILTER BEDS
TREATED FLUID STORAGE
HEATER
CHLORINATED ORGANICS (WASTE STORAGE TANK)

FIGURE 3.3.5 : TYPICAL PROCESS FLOW SCHEMATIC; TREATMENT OF CHLORINATED ORGANIC WASTES

SOURCE: SUNOHIO

PCBs. Low air emissions and potential for material recovery (e.g., PCB-free oil) are some of the main advantages cited for chemical dehalogenation.

Process Applications

There are only a small number of field applications at the present time, but chemical dehalogenation is viewed as an excellent potential process for the detoxification of chlorinated compounds. It appears to be viable for aqueous as well as non-aqueous wastestreams contaminated with chlorinated organics.

Economic Factors[3]

At the present time, treatment costs are considered economical for moderately contaminated waste streams but not for highly concentrated chlorinated organics. In the case of PCB-contaminated oils, the treatment costs are not competitive with other destruction options for concentrations greater than 6,000 ppm of PCBs.

Energy Requirements

The power requirements are unknown, but they would be predominantly for electricity to run pumps and accessories.

Resource Recovery Potential

Resource recovery can be realized with chemical dehalogenation. In the case of PCBs, once the chlorine is removed from the contaminated oils, the PCB-free oil can be recovered for reuse.

Environmental Factors[3]

Use of highly reactive chemical reagents is one of the major concerns in chemical dehalogenation processes. Proper handling procedures are a must to avoid accidents and personal injury to operating personnel.

Institutional Considerations

Chemical treatment of PCB-contaminated waste by dehalogenation poses no unusual institutional considerations. However, the dechlorinated organic waste may require further treatment prior to ultimate disposal.

ELECTRODIALYSIS

Process Description (Figure 3.3.6) [1]

Electrodialysis is a membrane process which concentrates ionic species present in the wastewater stream into a smaller volume through the application of an electrical driving force. Two different membranes must be used together: the anion-permeable membrane which permits the passage of anions only, while the cation-permeable membrane allows only cations to pass. While desalting brackish water remains the principal application of electrodialysis, the process is also becoming important in the treatment of a number of industrial effluents.

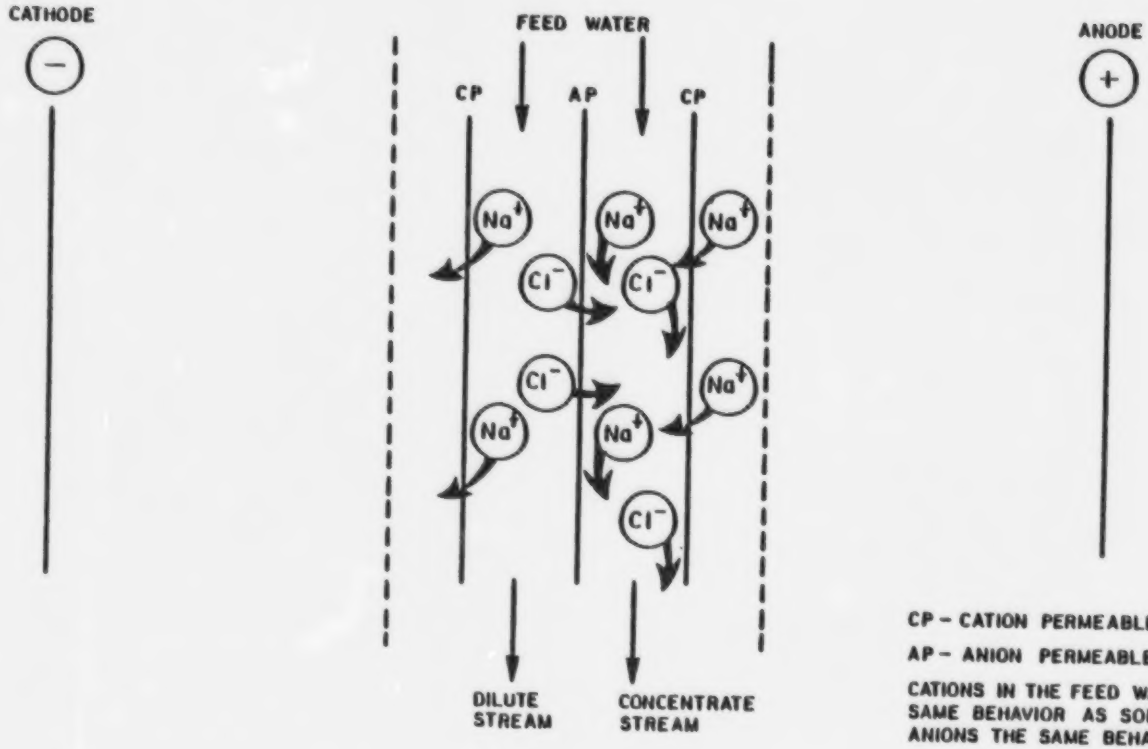
The feed water passes through compartments formed by the spaces between alternating cation-permeable (CP) and anion-permeable (AP) membranes held in a stack. At each end of the stack is an electrode having the same areas as the membranes. A direct current potential applied across the stack causes the positive and negative ions to migrate in opposite directions. Feed material is first filtered to remove suspended particles that could clog the system. An operating plant usually contains many recirculation, feedback and control loops and pumps to optimize the concentrations and pH at different points for the most efficient operation.[1]

Waste Inputs [1]

The process is effective for removing acids and metal salts. Appropriate for treatment of the following wastes (by UCD classification): 141-145.

Effluent and Residuals [1]

A dilute and a concentrated aqueous electrolyte stream exit the electrodialysis system. The dilute effluent may be suitable for direct discharge, while the concentrated effluent requires further treatment or an environmentally acceptable disposal method.


CATHODE
−
FEED WATER
CP
AP
CP
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Cl⁻
Na⁺
Na⁺
Cl⁻
Na⁺
Cl⁻
DILUTE STREAM
CONCENTRATE STREAM
ANODE
+

CP – CATION PERMEABLE MEMBRANE

AP – ANION PERMEABLE MEMBRANE

CATIONS IN THE FEED WATER SHOW THE SAME BEHAVIOR AS SODIUM (Na^+). AND ANIONS THE SAME BEHAVIOR AS CHLORIDE (Cl^-).

FIGURE 3. 3.6. : DIAGRAMMATIC REPRESENTATION OF ELECTRODIALYSIS

SOURCE: A.D. LITTLE, 1977

Implementation, Reliability [1]

Electrodialysis is a proven technology for separating and concentrating electrolyte solutions. Operating temperature, pH and chemical characteristics of the waste stream are some of the main factors affecting the performance of electrodialysis systems.

Process Applications [1]

Electrodialysis has been used for desalination since the 1950's. The largest number of installations is in the production of potable water from brackish well or river water. Hundreds of such units, some of which can handle more than $4000m^3$ per day, are in use throughout the world.

In the food industry, electrodialysis is used for desalting whey and deashing sugar. The chemical industry uses the technique for enriching or depleting solutions, and for removing mineral constituents from product streams.

Electrodialysis can be employed for the concentration and recovery of hydrochloric, sulfuric and other acids. Some metal finishers use electrodialysis to recover heavy metals from plating wastes. Sulfite pulp liquor has also been successfully treated by electrodialysis.

Energy Requirements [1]

Electrical requirements vary, but conventional desalination systems take about 5-8 kWh of energy for each 1,000 ppm reduction of salt in each $4m^3$ purified product water.

Economic Factors [1]

Both capital and direct operating costs are dependent on the volume of solution treated and on the amount of salts removed. Total water production costs of less than $\$0.40/m^3$ are reported for salt reduction from 2,000 ppm to 500 ppm in plants treating $4000m^3$/day or more. Other plants may have higher costs or may receive significant credits for reclaimed material.

A typical electrodialysis system to treat rinsewaters from an acid nickel plating line costs about \$12-40/m^3.

Resource Recovery Potential

Resource recovery potentials are good for concentrated electrolyte solutions.

Environmental Factors [1]

Hazardous components are not detoxified, only concentrated within the residual effluent stream. The product streams must be recycled, or otherwise disposed of. Since unwanted side-reaction of hydrogen gas formation takes place at the cathode while chlorine is generated at the anode, these gases may pose a hazard in an enclosed space.

Institutional Considerations

Although no unusual institutional considerations apply to electrodialysis, treatment of liquid effluents must be incorporated.

FILTRATION

Process Description (Figure 3.3.7)[1]

Filtration is a physical process whereby particles suspended in a fluid are separated by forcing the fluid through a porous medium. As the fluid passes through the medium, the suspended particles are trapped on the surface of the filter medium and/or within the body of the medium. Filter media can be a thick barrier of a granular material, such as sand, coke, coal, or porous ceramic; a thin barrier, such as a filter cloth or screen; a thick barrier composed of a disposable material such as diatomaceous earth for waste ash. The pressure differential to move the fluid through the medium can be induced by gravity, positive pressure, or vacuum. The intended application will indicate the selection of the appropriate filter.

Filtration is a well-developed liquid/solid separation process in the full-scale treatment of many industrial wastewaters and waste sludges. For the treatment of wastes, filtration can be used to perform two functions. These include suspended solids removal from a liquid waste stream to produce a purified liquid and a concentrated waste sludge cake.

Three filter types are available for solid/liquid separation and these include:

- Granular media filters. This process utilizes a bed of granular particles to remove suspended solids from aqueous waste streams.

- Fixed media, continuously renewed surface filtration categorized under this term are rotary drum vacuum filter, microstrainer, disk filter, and belt filter press.

- Chamber pressure filters. The filter press is the most common and representative of this group.

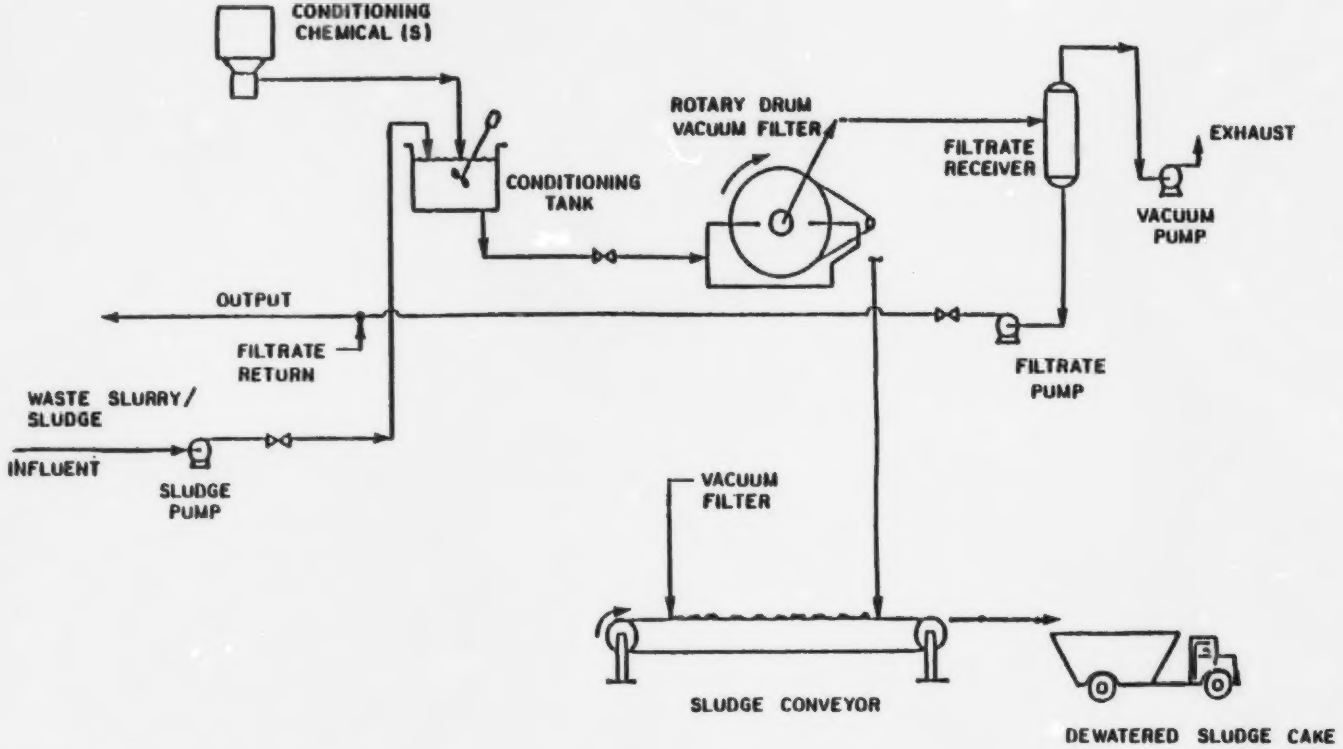

CONDITIONING CHEMICAL (S)
ROTARY DRUM VACUUM FILTER
FILTRATE RECEIVER
EXHAUST
CONDITIONING TANK
VACUUM PUMP
OUTPUT
FILTRATE RETURN
FILTRATE PUMP
WASTE SLURRY/ SLUDGE
INFLUENT
SLUDGE PUMP
VACUUM FILTER
SLUDGE CONVEYOR
DEWATERED SLUDGE CAKE

FIGURE 3.3.7 : VACUUM FILTRATION OF WASTE SLUDGE — TYPICAL PROCESS FLOW SCHEMATIC

SOURCE: A.D. LITTLE, 1977

Waste Inputs

Sanitary and hazardous waste sludges and slurries generated by pollution control systems. Appropriate for treatment of the following wastes (by UCD classification): 112-113; 122; 165; 167; 251; 261-262; 417; 431; 433; 441-447; 453-457; 528.

Effluent and Residuals[1]

Filtration generates an aqueous effluent with reduced suspended solids concentration. The process also produces a sludge or filter cake of relatively high solids concentration which requires ultimate disposal.

Implementation, Reliability

Filtration is a proven technology for removing suspended particles and for dewatering sludges for volume reduction. When considering the application of filtration processes, it is important to evaluate the two major objectives, which include the production of a purified liquid stream and the concentration of a slurry or sludge.

Process Applications[1]

The inorganic chemicals industry employs various forms of filtration to separate precipitated products from waste materials. They are commonly used in the manufacture of titanium dioxide, sodium dichromate, aluminum sulfate, and magnesium. The organic chemicals industry also employs filtration techniques, e.g., removal of acetylene carbon particles from aqueous quench streams, and removal of dye particles from reaction baths. Rotary vacuum filters are used to remove impurities from lube oils. Boiler feed water and many types of industrial process waters have stringent specifications on suspended solids. Filtration is often used in conjunction with precipitation, flocculation, and sedimentation to remove these solids. Filtration is also used as the final step in many industrial wastewater treatment plants.

Major applications are in the removal of suspended solids from wastewater streams and in the volume reduction (dewatering) of waste sludges and slurries. As tighter restrictions are placed on wastewater discharge, filtration will often be used after precipitation, flocculation, and sedimentation. Decreased availability of solid waste disposal sites will further encourage the dewatering of sludges prior to disposal. For example, sludge arising from the precipitation of heavy metals is more manageable and less costly if its volume is reduced.

While non-aqueous liquids can be subjected to filtration for the removal of suspended solids, highly viscous semi-liquids such as tars are generally not amenable to filtration.

Economic Factors [1]

The cost of purchasing and operating a vacuum filter or filter press is usually in the range of $25-100/tonne of solids dewatered (dry weight basis). For liquid purification, the cost of filtration by granular media filters usually varies from $0.07 - 0.40/m^3 of liquid treated.

Energy Requirements [1]

A vacuum filter system capable of dewatering 100m^3/day of sludge containing 4 tonnes of solids will have a power requirement of about 14kW.

Resource Recovery Potential

In the case of liquid waste filtration, the filtered effluent generally contains less than 10-15 mg/L suspended matter and therefore may be suitable for reuse. When filters are utilized for sludge dewatering, the concentrated sludge cake can be either extracted or washed with a suitable solvent to recover valuable materials contained in the sludge cake. If the sludge cake is mostly organic, it is usually combustible, thereby allowing recovery of the heat value.

Environmental Factors [1]

As a dewatering process, filtration only concentrates the wastes, hence reducing transportation and disposal costs. It is not designed to environmentally improve the sludge beyond making the wastes more amenable for landfilling or thermal destruction.

Institutional Considerations

No unusual institutional considerations apply to the use of filtration processes, however, ultimate disposal of waste residues and treatment of liquid effluents must be included.

HYDROLYSIS

Process Description (Figure 3.3.8) [1]

Hydrolysis is a chemical process used to treat organic matter such as esters of fatty acids. The process generally refers to double decomposition reactions with water of the type: $xy + H_2O = Hy + xOH$. Hydrolysis is usually carried out at elevated temperatures and pressures, often with catalysts. It is a process that has been used since the earliest days of soap making. Hydrolysis is potentially applicable to a wide range of waste forms and compositions.

Inorganic hydrolytic reactions in which a salt reacts with water to form an acid and a base are usually the reverse of neutralization. The trivalent metal salts of aluminum and iron (Al^{+3} and Fe^{+3}) undergo a different mechanism of hydrolysis: during a series of reactions with water, various multivalent hydrous oxides are formed. These charged species are important to floc development and coagulation during the treatment of turbid waters.

Organic hydrolysis may take on a broader aspect including reactions not involving water. An example includes the addition of an alkali to solution and the subsequent formation of the alkali salt of an organic acid.

Waste Inputs [1]

Feed streams can be either liquids or gases, aqueous or non-aqueous solutions, slurries, sludges, or tars. Both organic and inorganic chemicals can be hydrolyzed. Appropriate for the treatment of the following wastes (by UCD classification): 221-224; 251.

Effluent and Residuals [1]

Depending upon the particular hydrolytic reaction, treatment products can be in the liquid, solid, or gaseous state. In some cases, more than one product phase can result. Some potentially toxic residues may also result.

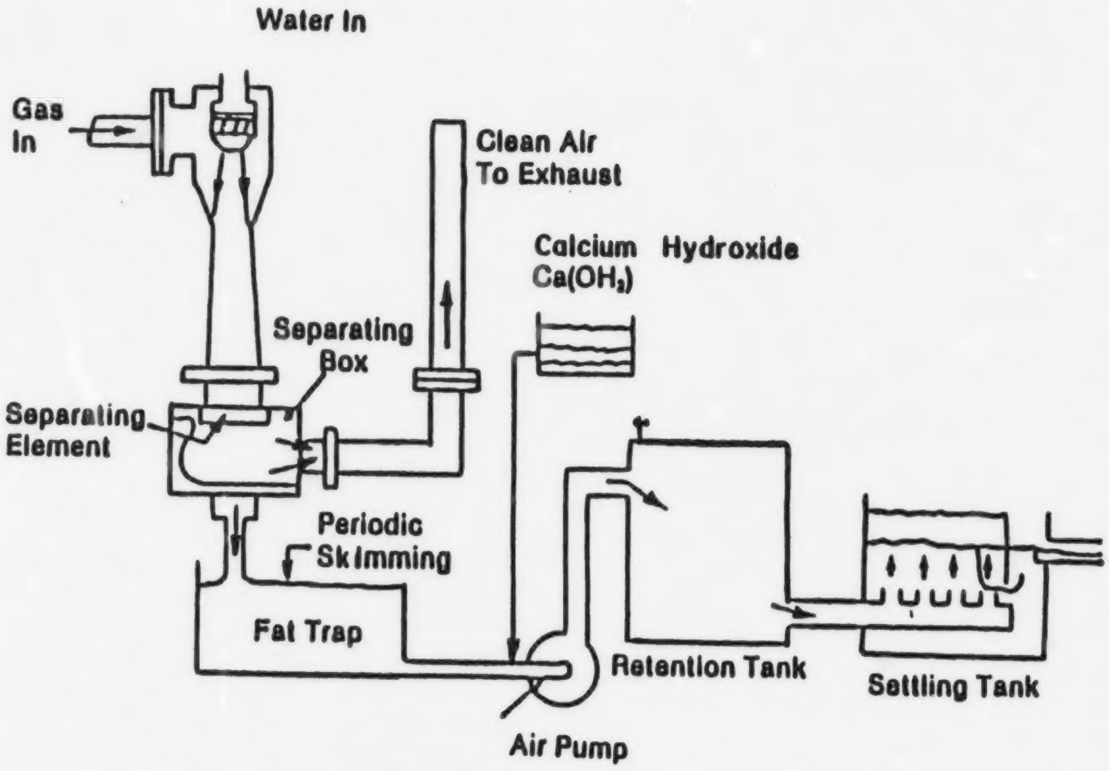

Water In
Gas In
Clean Air To Exhaust
Calcium Hydroxide Ca(OH₂)
Separating Box
Separating Element
Periodic Skimming
Fat Trap
Retention Tank
Settling Tank
Air Pump

FIGURE 3.3.8 : HYDROLYSIS OF FATS

SOURCE: A.D. LITTLE, 1977

Implementation, Reliability[1]

Hydrolysis technology is generally well defined and understood. A wide range of treatment schemes are applicable, including batch vs. continuous and tank vs. tower. The process control parameters for hydrolysis include temperature, pressure, pH, and the use of catalysts.

Process Applications[1]

The oldest application of hydrolysis is in the production of soap from heated fats in the presence of caustic (known as saponification). Hydrolysis is also used commercially for the manufacture of a variety of organics (e.g., production of phenol from chlorobenzene; production of ethylene oxide from ethylene glycol or ethylene chlorohydrin).

Waste treatment applications at present are not widespread. However, in the petroleum industry, the sludge from acid treatment of light oils is often hydrolyzed to recover sulfuric acid for reuse, while the other product, a tarry acid oil, may be concentrated and burned as fuel. Hydrolysis has also been used for detoxifying waste streams containing carbamates, organophosphorus compounds, and other pesticides.

Hydrolytic waste treatment processes that have shown promise in the laboratory include acid hydrolysis of waste paper to sugar; conversion of organic sludge to animal feed; and decompositon of polyurethane foam to toluene diamine and a polyol. For waste management, hydrolysis can be adapted to handle liquids, gases, or solids. Wide application for inorganic materials does not appear likely, but hydrolysis is suitable for a broad range of aliphatic and aromatic organics.

Economic Factors[1]

The capital investment and operating costs are highly dependent on the specific process details. Capital investment figures for different processes range from about $2500-20,000/tonne of material handled daily. Operating costs may range from $0.66 - 3.30/kg.

Energy Requirements [1]

Energy requirements vary considerably with each particular application but are generally high. Steam requirements for production of fatty acids are approximately 280kJ/kg of product. Production of TiO_2 fromTi $(SO_4)_2$ requires about 3500 kJ steam/kg. of TiO_2 produced.

Resource Recovery Potential

Some material recovery potential exists.

Environmental Factors [1]

Hydrolytic reactions are capable of producing toxic byproducts in any physical form. For example, hydrolysis of the pesticide parathion results in the generation of a hazardous compound that remains in solution. When high temperatures or high pressures are used, undesirable gaseous products can result. Solid residuals, such as tars and sludges, can create difficult disposal problems.

Institutional Considerations

The institutional considerations of applying hydrolysis include ultimate disposal of waste residues, treatment of liquid effluents, potential odours and noise and general nuisance problems.

ION EXCHANGE

Process Description (Figure 3.3.9)[1]

Ion exchange involves the removal of ionic species, principally inorganic, from an aqueous or partially aqueous phase. Its earliest applications were involved with water softening and sugar crystallization. Ion exchange involves the interchange of ions between an aqueous solution and a solid material (the "ion exchanger"). Once the process is complete, the exchanger is exposed to a second aqueous solution of different composition which removes the ions picked up by the exchanger.

When the aqueous solutions comes in contact with the exchanger, the active sites are partially or completely used up by that ion. To regenerate the exchanger, a sufficiently concentrated solution of the exchanger ions is placed in contact with the unit. Ion exchange provides a mechanism for removing undesirable ions from a waste stream and for tranferring those ions, at higher concentration, to another aqueous stream.

Although today's ion exchange technology is dominated by synthetic ion exchangers, many of which are highly specific for certain ions, natural ion exchangers are also used in wastewater treatment. For example, clinoptilotile, a naturally occurring zeolite, is very effective for the removal of ammonium ions from municipal and industrial effluents.

In carrying out ion exchange reactions in a column or bed operation there are four operations carried out in a complete cycle:

- service (exhaustion)
- backwash
- regeneration
- rinse

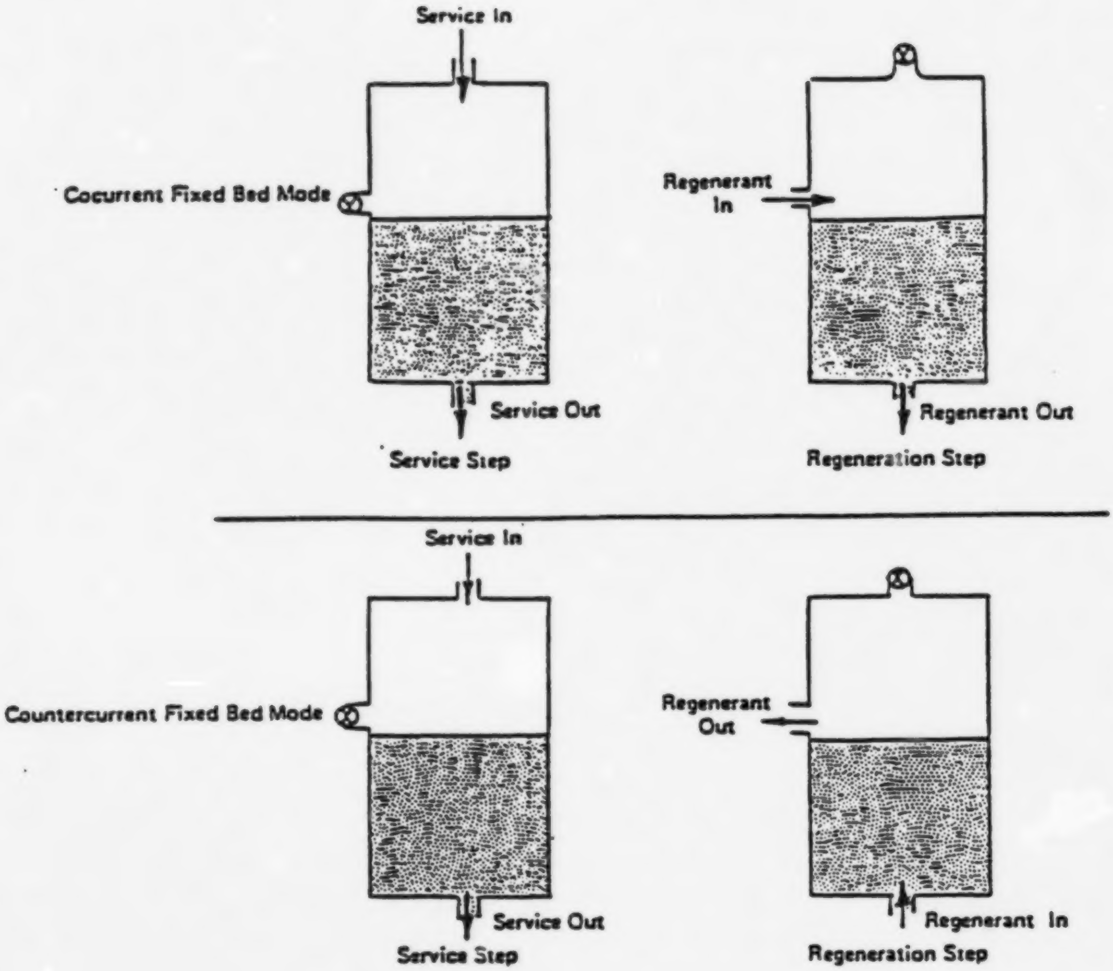

Service In
Cocurrent Fixed Bed Mode
Service Out
Service Step
Regenerant In
Regenerant Out
Regeneration Step
Service In
Countercurrent Fixed Bed Mode
Service Out
Service Step
Regenerant Out
Regenerant In
Regeneration Step

FIGURE 3.3.9 : OPERATIONAL MODES FOR ION EXCHANGE

SOURCE: A.D. LITTLE, 1977

Waste Inputs [1]

Ion exchange is applicable to aqueous streams and to single-phase partially aqueous waste streams, such as ethylene glycol-water mixtures. It is well suited for removal of heavy metals and toxic anions from dilute waste streams. The upper concentration limit for efficient operation is approximately 4000 mg/l. Appropriate for treatment of the following wastes (by UCD classification): 112-113; 122; 141-145; 147; 511.

Effluent and Residuals [1]

Ion exchange processes generate two liquid streams:

1. A purified product stream of high volume which is depleted in the species being removed.

2. A small concentrated volume of spent regenerant containing a high concentration of the species removed.

   The product stream can be recycled but the spent regenerant requires further treatment or ultimate disposal.

Implementation, Reliability [1]

Ion exchange is a well-proven and versatile technology, particularly suitable for the removal of heavy metals and toxic anions from dilute waste streams. To ensure high performance and resin longevity, proper pretreatment is essential.

Process Applications [1]

Industries employing ion exchange for wastewater treatment (mainly for the removal and/or recovery of heavy metals) include electroplating and metal finishing facilities, photographic processors, chlor-alkali plants, pigment manufacturers, chemical fertilizer complexes and chemical manufacturing establishments.

Unique ion exchange resins derived from cellulose for the recovery of proteins from food processing wastewater (e.g., cheese and soy whey, meat, fish and poultry processing effluents) are also available. Some of the promising newer applications of ion exchange include the removal of cyanides and boron.

Economic Factors [1]

Capital costs are expected to be in the range of $250,000-$1,000,000 with a substantial investment in resin. Operating costs might be in the vicinity of $1.30 - 5.00/m^3.

Energy Requirements [1]

Energy requirements are low, consisting primarily of electricity for pumping solutions.

Resource Recovery Potential

Material recovery for reuse offers good potential. Recycle of the product stream is possible as well as the recovery and reuse of removed species in the regenerate.

Environmental Factors [1]

Volume reduction results from ion exchange, and in addition non-toxic effluents are produced. The purified product water is generally suitable for discharge to sewers. The concentrated regeneration stream requires further treatment for recovery or safe disposal. Air emissions are essentially zero. If recovery is not possible, spent resins create secondary disposal problems. Hazardous constituents (if present) are not detoxified, just concentrated.

Institutional Considerations

Ion exchange processes pose no unusual institutional problems besides the ultimate disposal of waste residuals. Treated effluent may also require further purification.

NEUTRALIZATION

Process Description (Figure 3.3.10) [1]

Neutralization is a common liquid-phase chemical treatment process in which an acid is mixed with a base to neutralize the waste stream modifying its acidity or alkalinity through pH control. In addition to adjusting waste pH to a value close to 7 (neutral pH), neutralization generally results in the formation of insoluble salts containing the waste's components.

Simply, the process of neutralization is the interaction of an acid with a base. The typical properties exhibited by acids in solution are due to the hydrogen ion (H^+). Similarly, alkaline (or basic) properties are a result of the hydroxyl ion (OH^-). In aqueous solutions, acidity and alkalinity are defined with respect to pH, where $pH = -\log(H^+)$ and, at room temperature, $pH = 14 + \log(OH^-)$. In the strict sense, neutralization is the adjustment of pH to 7, at which level the molar concentrations of hydrogen and hydroxyl ions are equal. Solutions with excess hydroxyl ion concentration (pH 7) are said to be basic; solutions with excess hydrogen ions (pH 7) are acidic. Since adjustment of the pH to 7 is not often practical or even desirable in waste treatment, the term "neutralization" is sometimes used to describe adjustment of pH to values other than 7.

The addition of appropriate quantities of the neutralizing agent is monitored and adjusted by pH measurement and control. In batch treatment, an operator can take samples, measure the pH and add the required dose of the acid or alkali. In a continuous flow system, automatic pH monitors check the acidity or alkalinity and control the feeding of neutralizing agent. The number of neutralization units required and the location of pH sensors are determined by the stability of the waste stream pH.

Waste Inputs [1]

Although neutralization is a liquid phase process, it can also treat gaseous and solid waste streams. Neutralization can be used to treat both inorganic and organic waste streams that are either excessively acidic or alkaline.

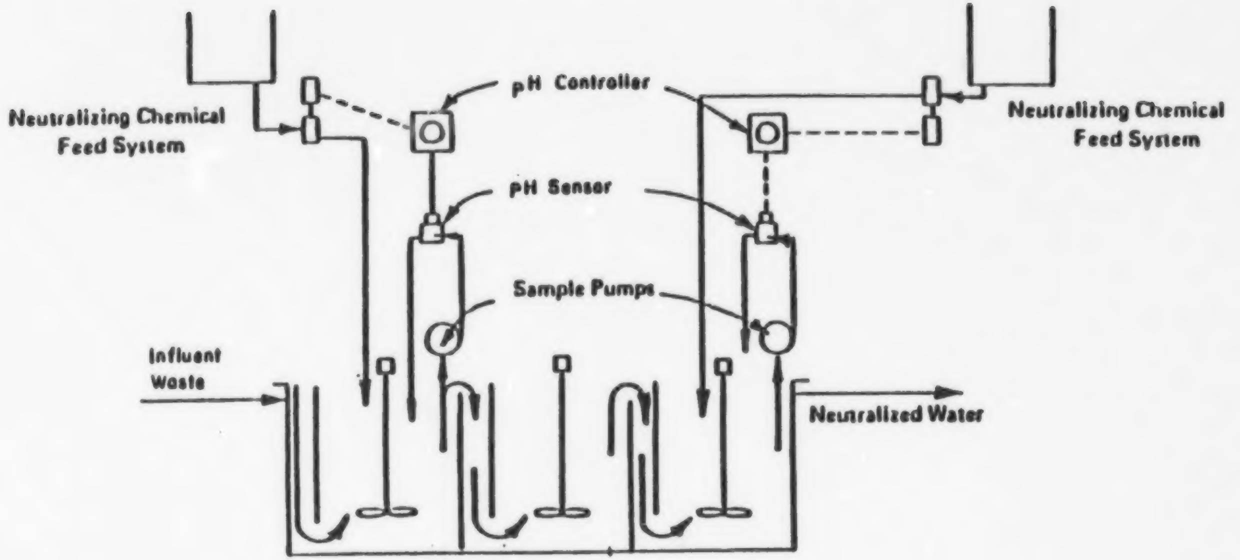

Neutralizing Chemical Feed System
pH Controller
Neutralizing Chemical Feed System
pH Sensor
Sample Pumps
Influent Waste
Neutralized Water

FIGURE 3.3.10 : CONTINUOUS FLOW NEUTRALIZATION — PROCESS SCHEMATIC

SOURCE: A.D. LITTLE, 1977

Compounds which can be treated include carboxylic acids, sulfonic acids and phenols. Appropriate for treatment of the following wastes (by UCD classification): 111-113; 121-123; 131-133; 284-285; 511.

Effluent and Residuals [1]

Neutralization produces a treated (neutralized) aqueous effluent and may produce a solid residue. The products of neutralization can be liquid, solid or gaseous. The chemical species present in the neutralized stream may include the original components of the waste stream in addition to material from the neutralizing agent. The concentrations of the individual species will depend on the solubility of the products formed during reaction.

Implementation, Reliability [1]

Neutralization (or more generally pH control) is a technically and economically proven process, currently in full-scale use in many industries. It has wide applicability to waste streams of diverse physical and chemical compositions and is a component of almost every waste treatment facility.

The selection of a neutralizing agent is dictated by a number of factors such as economics, availability, and process compatibility. Commonly, the choice of an acid for neutralizing alkaline wastes is between sulfuric acid and hydrochloric acid. The neutralization process is subject to the influence of temperature and the resulting heat effects are common to most chemical reactions. Generally, in water-based reactions, increasing the temperature of the reactants increases the rate of reaction. In neutralizing, the interaction of acid and alkali is frequently exothermic.

Process Applications [1]

The process is in full-scale use throughout many industries (e.g., pulp and paper, petroleum refining, and inorganic chemicals). It is used to treat spent acids, pickle liquors, plating wastes, and acid mine drainage. It can be used on almost any stream requiring pH adjustment. Neutralization is and will continue to be a routine and accepted part of waste management.

Economic Considerations [1]

Capital investment requirements are highly variable, depending upon the characteristics and volume of the stream to be treated. Operating costs range between \$0.05/m^3 to \$1/m^3.

Energy Requirements [1]

Energy requirements are primarily for electricity to run pumps and stirrers.

Resource Recovery Potential

Resource recovery is practical only in situations where the precipitate is in a concentrated and highly pure form and can be recovered in a cost-effective manner.

Environmental Factors [1]

Dissolved solids concentrations increase when neutralizing acids, whereas solids dissolution results from neutralizing alkaline streams. Sulfate and chloride anions result from neutralizing their respective acids, and discharge limits must be met for these species. Sodium and calcium cations result from neutralizing alkaline solutions, and although no discharge limits exist, these cations influence water hardness and scaling. Some neutralization processes generate toxic gases. Ultimate disposal of residues may be necessary.

Institutional Considerations

Neutralization poses no unusual institutional considerations besides the ultimate disposal of waste residues and the treatment of liquid effluents.

CHEMICAL OXIDATION

Process Description[1]

Chemical oxidants in wide usage today include chlorine, ozone and hydrogen peroxide. Furthermore, treatment with these chemicals may also be advantageously combined with other techniques; e.g. UV irradiation, to obtain even more effective destruction of toxic and hazardous compounds.

Ozone is a powerful oxidizing agent that is effective for colour removal, disinfection, taste and odour removal and for the oxidation of many complex organics (e.g., pesticides, cyanides, phenols, organometallic complexes). Usage of ozone varies with the stream being treated. Due to its inherent instability, ozone must be generated onsite.

Well known applications of chlorine oxidation include the destruction of phenols and cyanides (see Fig. 3.3.11). Chlorine oxidation reactions and kinetics are influenced by a multitude of process variables, most notably pH.

In addition to chlorine and its more readily storable form, i.e., bleach, another source of chemical oxidation power for the destruction of organics is chlorine dioxide. According to various publications, chlorine dioxide is a selective oxidant; it reacts with cyanides, phenols, sulfides and mercaptans but not with alcohols, glycols, ketone, etc. Because of its high cost, chlorine dioxide usage is generally confined to selective polishing in order to destroy low concentrations of specific compounds.

Chlorinolysis is a relatively novel application of chlorine in industrial pollution abatement. The process involves the exhaustive chlorination of highly chlorinated residues, giving carbon tetrachloride and hydrogen chloride as the main reaction products. The main reaction products may be recovered and reused or sold.

Du Pont's Kastone process is one of the best known treatment methods using hydrogen peroxide. It is particularly suitable for small electroplaters employing zinc and cadmium cyanide baths. The process destroys cyanides and precipitates heavy metals.

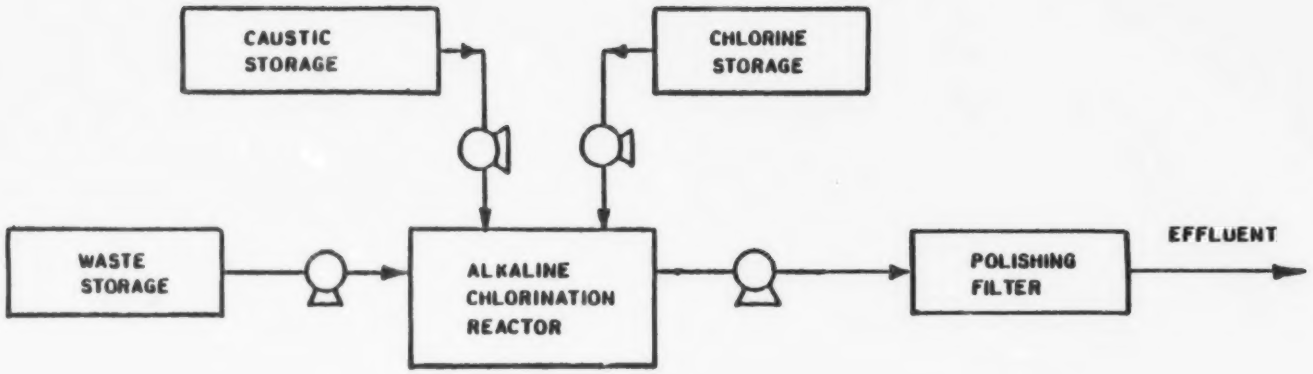

CAUSTIC STORAGE
CHLORINE STORAGE
WASTE STORAGE
ALKALINE CHLORINATION REACTOR
POLISHING FILTER
EFFLUENT

FIGURE 3.3.11 : TYPICAL PROCESS FLOW SCHEMATIC — CHEMICAL OXIDATION OF CYANIDE BEARING WASTES

SOURCE: A.D. LITTLE, 1977

Caro's acid, or peroxymonosulfuric acid, is another potent oxidant that has been successfully utilized for the destruction of cyanides in a variety of industrial effluents, e.g., blast furnace blowdown.

Waste Inputs [1]

Liquids are the primary waste for treatment by chemical oxidation. The most powerful oxidants are relatively non-selective; therefore, any easily oxidizable material in the waste stream will be treated. Oxidation has limited use with slurries, tars, and sludges. Appropriate for treatment of the following wastes (by UCD classification): 111-113; 121-123; 131-133; 146-147; 221-213; 214-217; 221; 223; 251; 281-283; 286-288.

Effluent and Residuals [1]

Chemical oxidation produces an effluent stream containing lower concentrations of the original pollutants as well as a wide range of oxidation products. A precipitated solid residual may also be generated. Depending on prevailing environmental regulations, the effluent may be discharged or given further treatment. Precipitated solids of course require ultimate disposal if recovery and utilization are not possible.

Implementation, Reliability [1]

Chemical oxidation technology using chlorine, ozone, hydrogen peroxide or Caro's acid is well established for large-scale applications, particularly for the destruction of phenols and cyanides. While the equipment employed for simple chlorination and in the Kastone process is relatively simple, a complete ozonation package is quite complex, requiring ozone generators, gas injection system, reaction vessels, pumps, instrumentation, etc.

Process Applications [1]

Chemical oxidation has long been used for water treatment and odor removal from gaseous streams. Its usage in municipal wastewater treatment is growing with each passing year. Petroleum refineries, steel mills, pulp and paper mills, photographic processors, naval stores, textile mills and chemical manufacturing complexes are just some of the many industries which employ one or more of the above chemical oxidation techniques for wastewater treatments. Decolourization, removal of phenols and cyanides, and detoxification are the usual objectives of chemical oxidation in these industries.

Economic Factors [1]

A facility for chemical oxidation of $4m^3$ of highly concentrated cyanide waste from a plating operation using batch alkaline chlorination may require a capital investment of $250,000 - 1,000,000. For a less highly concentrated waste, (100 ppm copper cyanide and 100 ppm sodium cyanide), the operating cost would be about $45 - 65/$m^3$. Costs could be lowered if the daily flow rate were to increase and the treatment operation could be continuous rather than batch.

Resource Recovery Potential

The potential exists for resource recovery only in situations where the recoverable product has value. A good example is afforded in the photographic industry where spent solutions containing ferrocyanides are regenerated by some processors with ozone to ferricyanides which are then reused.

Energy Requirements [1]

Total energy consumption varies according to the process and waste being treated. While energy requirements are generally low for chlorination, they can be high for ozonation.

Environmental Impacts [1]

Chemical oxidations can create a residue (e.g., heavy metal precipitates, insoluble cyanide complexes) requiring ultimate disposal. Depending on the efficiency of the oxidation process, the treated liquid may be discharged into a receiving stream or given further treatment.

Institutional Considerations

Chemical oxidation processes create ultimate disposal requirements for waste residues and further treatment for liquid effluents.

PRECIPITATION, FLOCCULATION, AND SEDIMENTATION

Process Description (Figure 3.3.12) [1]

Precipitation, flocculation, and sedimentation are discussed as a single process, because in waste treatment they are most commonly used together to reduce soluble and insoluble matter. Precipitation, flocculation, and sedimentation are fully developed processes currently used in a wide variety of industrial processing and waste treatment applications. They can be quite readily applied to a variety of wastes for the removal of precipitable substances, such as heavy metals and for the removal of suspended particles in the liquid. Although the process theoretically can be used to treat non-aqueous liquids, such applications are very rare. Precipitation, flocculation, and sedimentation are generally unsuitable for treating heavy slurries, thickened sludges, and tars.

- **Precipitation:** Precipitation is a physical-chemical process whereby some or all of the substance in solution is transformed into a solid phase for removal.

- **Flocculation:** The terms "flocculation" and "coagulation" are used indiscriminately and interchangable to describe the process by which small, unsettleable particles or colloidal matter in a liquid are made to agglomerate into larger, more settleable particles.

- **Sedimentation:** Sedimentation is a purely physical process whereby suspended particles in a liquid settle by means of gravity and inertia acting on both the particles suspended in the liquid and on the liquid itself.

Recent developments in precipitation and flucculation include the Sulfex process for removing heavy metals from wastewaters, precipitation of proteins with lignosulfonic acid and the coagulation of suspended solids in food processing wastes with chitosan.

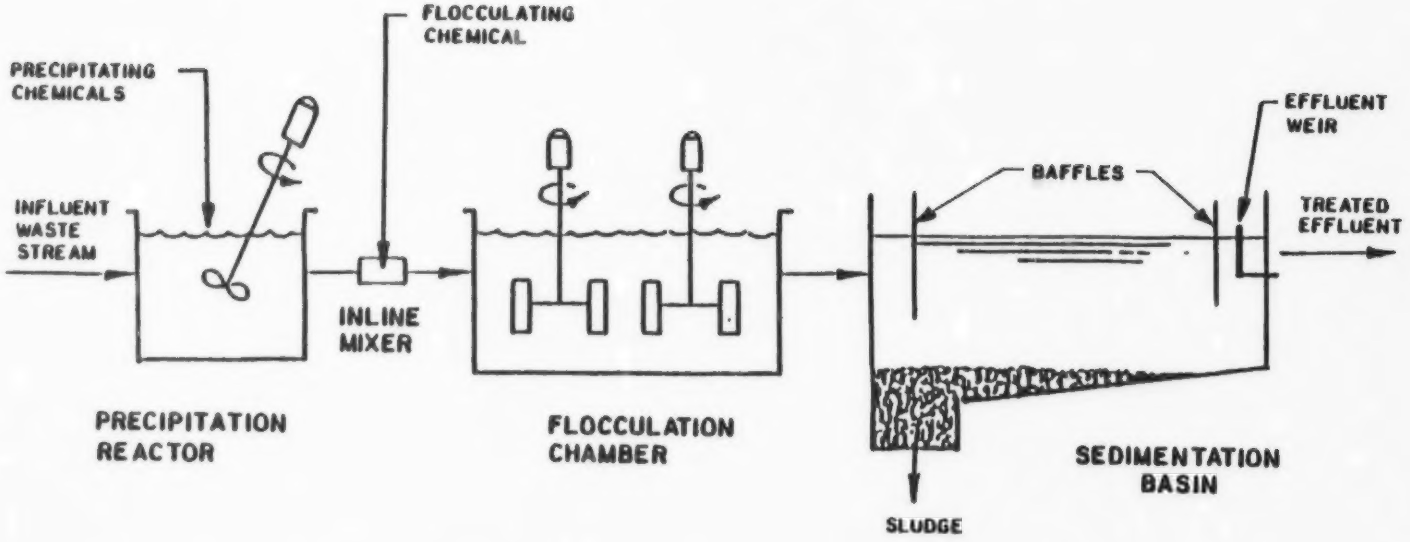

PRECIPITATING CHEMICALS
FLOCCULATING CHEMICAL
EFFLUENT WEIR
BAFFLES
INFLUENT WASTE STREAM
TREATED EFFLUENT
INLINE MIXER
PRECIPITATION REACTOR
FLOCCULATION CHAMBER
SEDIMENTATION BASIN
SLUDGE

FIGURE 3.3.12 : TYPICAL PROCESS FLOW SCHEMATIC – PRECIPITATION, FLOCCULATION, AND SEDIMENTATION

SOURCE: A.D. LITTLE, 1977

Waste Inputs [1]

Aqueous waste streams with suspended solids and added chemical flocculants to aid coagulation are the waste inputs. Appropriate for treatment of the following wastes (by UCD classification): 111-113; 121-123; 131-133; 211-213; 214-217; 221-223; 251; 417; 431; 433; 441-445; 447.

Effluent and Residuals

Precipitation, flocculation, and sedimentation processes produce relatively clear supernatant liquid, and a solid or sludge residue. The treated aqueous effluent may be suitable for discharge or may require further treatment. The sludge residual can be further dewatered and then utilized or disposed.

Implementation, Reliability[1]

Precipitation, flocculation, and sedimentation are proven technologies which are currently well developed for full scale treatment and many wastes containing particulates and/or soluble heavy metals. Research into the implementability of these reactions usually entails no more than simple laboratory tests.

Process Applications [1]

The processes have been widely used for a variety of industrial applications, such as in the manufacture of organic chemicals, pigments, the preparation of metal ores and the purification of sugar. Practically every industry that discharges a process wastewater stream contaminated with suspended and/or precipitable pollutants employs some form of precipitation, flocculation, and/or sedimentation. Examples are: removal of heavy metals from iron and steel industry wastewaters; removal of cyanide from plating and steel industry effluents; removal of fluoride from aluminum production wastewater, and removal of heavy metals from copper smelting and refining wastewaters, and from metal finishing industry discharges.

In determining the applicability of precipitation, flocculation, and sedimentation to specific waste streams, detailed research and development are usually unnecessary. Past experience and simple laboratory jar tests are usually sufficient to determine applicability.

Economic Factors [1]

A large (over 2200 - 22000m^3 per day) system employing precipitation, flocculation, and sedimentation and using moderate dosages of precipitating/flocculating agents will usually treat wastewater at a cost of $0.13 - 1.00 per m^3.

Small systems (less than 2200m^3 per day) using high dosages of precipitating/flocculating agents may have costs that are higher, but these generally do not exceed $1.60 per m^3.

Energy Requirements [1]

Energy consumption is very low compared to other processes.

Resource Recovery Potential

In certain situations, either the clear supernatant water or the resultant sludge can be utilized. For example, sludge obtained from the treatment of food processing wastes is generally suitable for use as animal feedstuff. Sometimes it is economically feasible to recover heavy metals from plating sludges.

Environmental Factors [1]

In addition to the sludges which require treatment/disposal, there exists potential for adverse reactions with some complex wastes producing toxic gases or other hazardous products. The effluent stream may require additional treatment as well.

Institutional Considerations

No unusual institutional considerations are required besides the ultimate disposal of waste residues and the treatment of liquid effluents.

CHEMICAL REDUCTION

Process Description[1]

Reduction-oxidation, or "redox" reactions are those in which the chemical oxidation state of one or more reactants is raised while that of another is lowered. In waste treatment, chemical reduction is employed to lower the oxidation state of a substance in order to reduce its toxicity, reduce its solubility, or transform it into a form that can be easily removed utilizing basic separation techniques.

A common example illustrating the use of chemical reduction is the removal of hexavalent chromium from metal plating, tannery, tinning, etc. effluents (see Fig. 3.3.13). In the first step, the pH of the effluent is lowered to 2-3 and a reducing agent (e.g., sodium metabisulfite, ferrous sulfate or sulfur dioxide) is added to reduce the hexavalent chromium to the trivalent form. Sulfur dioxide is most often used because it is easy to handle and store. In water the gas dissolves and yields sulfurous acid. The reduction reaction may be summarized as:

$$2H_2CrO_4 + 3H_2SO_3 = Cr_2(SO_4)_3 + 5H_2O$$

After reduction is completed, the pH of the waste is brought up to 8-9 and the chromium precipitates out as chromium hydroxide.

Although sulfur dioxide or sodium metabisulfite are the two most common reducing reagents in the removal of hexavalent chromium, ferrous sulfate may also be advantageous in some instances; for example, at steel mills where waste pickle liquor from sulfuric acid pickling is available.

During the past few years, sodium borohydride ($NaBH_4$), a mild but selective reducing agent, has also gained recognition in pollution control, particularly for the removal of metals from a large array of process solutions and wastewaters. The metallic ions involved are reduced directly to insoluble elemental metal, giving a compact precipitate which can be readily separated from the solution. In current applications, initial metal concentrations range from 2-120 mg/L with final concentrations as low as (c. 0.1 mg/L) following treatment. Two of the most environmentally significant uses of sodium borohydride are in the reduction of mercury and lead to near nondetectable levels.

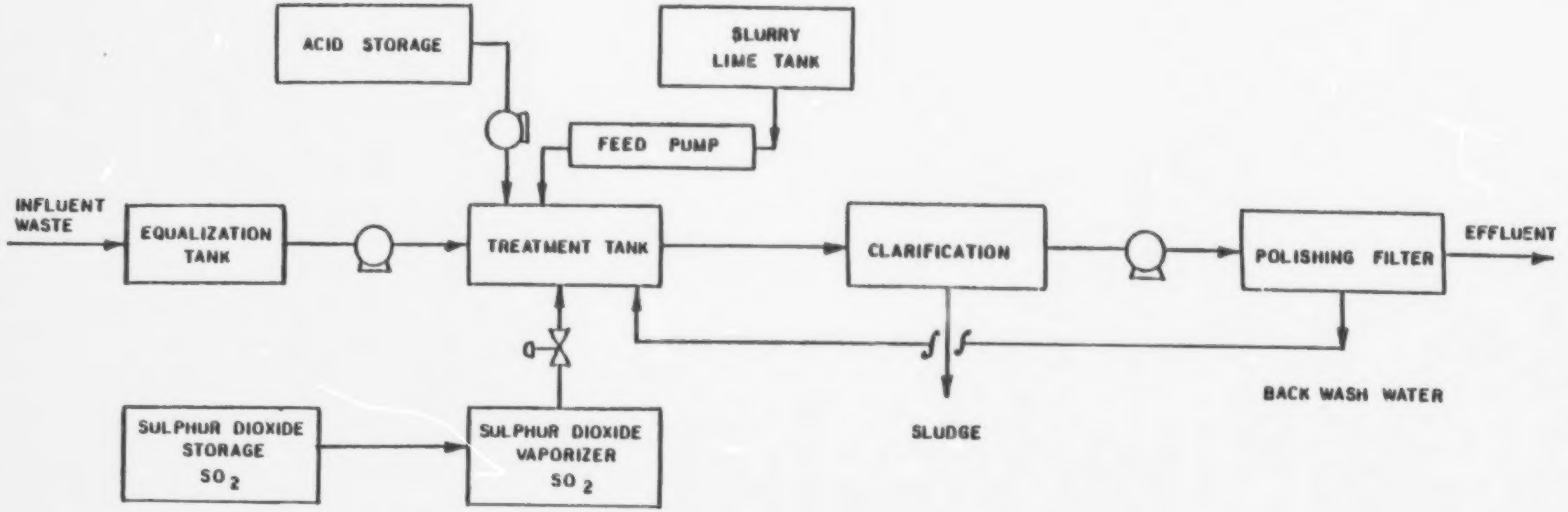

ACID STORAGE
SLURRY LIME TANK
FEED PUMP
INFLUENT WASTE
EQUALIZATION TANK
TREATMENT TANK
CLARIFICATION
POLISHING FILTER
EFFLUENT
SULPHUR DIOXIDE STORAGE SO 2
SULPHUR DIOXIDE VAPORIZER SO 2
SLUDGE
BACK WASH WATER

FIGURE 3.3.13 : TYPICAL PROCESS FLOWSHEET FOR CHEMICAL REDUCTION

SOURCE: A.D. LITTLE, 1977

When a solution containing a dissolved metal is contacted with a more active metal, the less active species is reduced to its metallic form by spontaneous electrochemical reduction and deposits on the more active metal. For example, by passing a waste stream containing mercury ions through a bed of zinc, the zinc acts as a reducing agent. Metallic mercury is deposited in the bed while zinc ions enter the solution. The same mechanism is responsible for the removal of copper when a copper-containing solution is passed through columns or beds packed with scrap iron. In the photographic industry, recovery of silver with steel-wool packed cartridges is a well-established process.

Waste Inputs [1]

Liquids are the main wastes treated by reduction. The most powerful reagents are relatively non-selective; therefore any easily reducible material in the waste stream will react. Gases have been treated by reducing solutions in small scale operations. Reduction has limited application with slurries, tars, and sludges. Appropriate for treatment of the following wastes (by UCD classification): 111-113; 121-123; 131-133; 146; 211-213; 214-217; 221; 251.

Effluent and Residuals [1]

Chemical reduction produces an aqueous effluent and may produce a precipitated solid residue. The effluent often requires neutralization prior to disposal.

Implementation, Reliability [1]

The technology for large-scale application is well developed, especially when the wastes contain chromium (VI). The equipment required is relatively simple, requiring only storage, metering, mixing, pumping, and instrumentation.

Process Applications [1]

The application of chemical reduction techniques to the treatment of industrial wastes are well-established, especially for effluents from plating and chrome tanning operations containing hexavalent chromium, as described above. Removal and recovery of mercury from chlor-alkali effluents can be achieved by using zinc-packed beds, while the recovery of silver with commercially available steel-wool packed cartridges is widely practiced by photoprocessors. Metal recovery is one of the chief advantages cited for employing sodium borohydride.

Economic Factors [1]

A facility for chemical reduction of $8m^3$ per day of chromium (VI) waste from a plating operation, using batch sulfur dioxide treatment would require a capital investment of about $250,000 - $750,000. The estimated annual cost for owning and operating this treatment system is approximately $93,000 or $50/$m^3$.

Energy Requirements [1]

Total energy consumption, not including the energy required to produce the chemicals, is low for chemical reduction. The requirements include power for pumping and mixing the wastes and the reducing agent.

Resource Recovery Potential

The possibility of metal recovery exists if economics warrant it.

Environmental Factors [1]

A disadvantage of chemical reduction is that it may introduce new ions into the effluent that might necessitate further treatment.

Institutional Considerations

Chemical reduction creates institutional problems associated with the ultimate disposal of waste residues and the further treatment of liquid effluents.

REVERSE OSMOSIS

Process Description (Figure 3.3.14) [1]

Reverse osmosis (RO) is a process which employs a semi-permeable membrane to remove solutes from solution using pressure as the driving force. In order to obtain reasonable flowrates through the membranes, prevailing pressures usually range from 2000 to 6000 kPa. Although cellulose acetate is still widely used, membranes made from other materials, notably aromatic polyamides, are finding an ever-growing application. Early reverse osmosis units were based on flat membrane sheets in arrangements similar to that of the plate-and-frame filter press. However, more efficient assemblies in the form of scrolls, straight tubular, helical tubular and hollow fibers have since emerged.

Factors affecting the performance of reverse osmosis systems include temperature, pH, concentration polarization, membrane compaction, fouling or scaling tendencies and the presence of chlorine. To avoid membrane plugging and to ensure long membrane life, it is important to remove oils, suspended solids, etc. by proper pretreatment. Fouling and scale formation can be controlled by periodic flushings.

Waste Inputs [1]

Reverse osmosis processes are used to treat aqueous solution containing dissolved species, both organic and inorganic. Appropriate for treatment of the following waste (by UCD classification); 141-145.

Effluent and Residuals [1]

Reverse osmosis produces two aqueous waste streams, a concentrated reject stream and a purified permeate.

Implementation, Reliability [1]

Reverse osmosis is a proven technology that should be considered for treatment of aqueous waste streams containing dissolved organic and inorganic species. Successful facilities are in operation for desalination of ocean waters (TDS 30-40,000 mg/L).

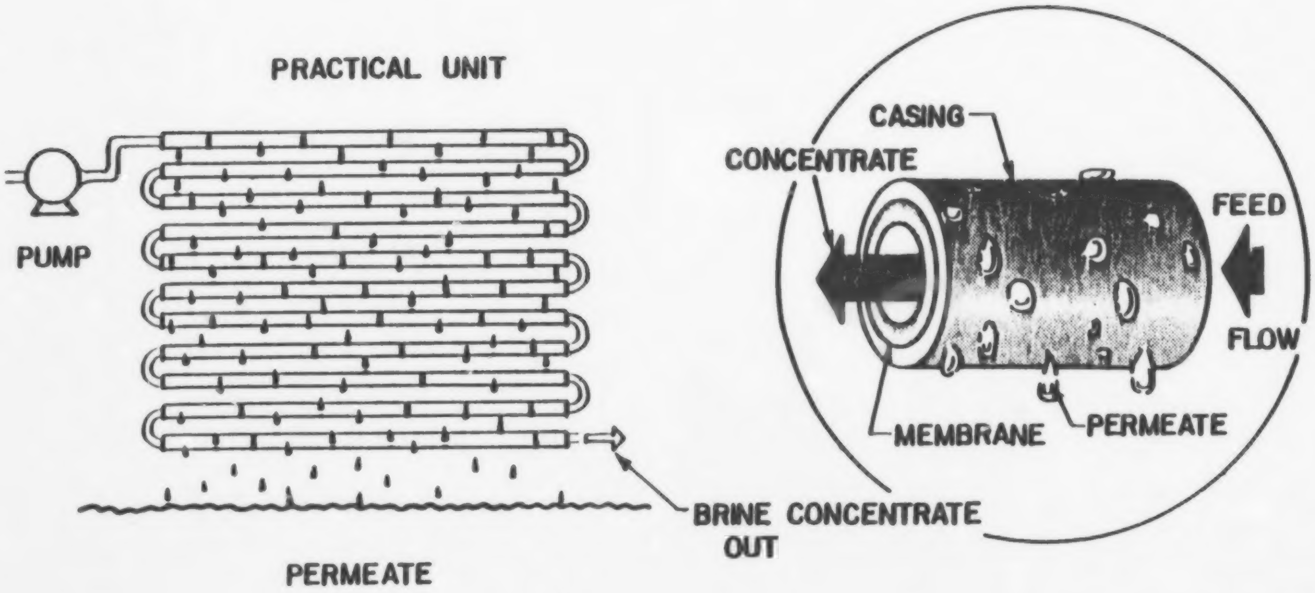

PRACTICAL UNIT
PUMP
PERMEATE
BRINE CONCENTRATE OUT
CASING
CONCENTRATE
FEED
FLOW
MEMBRANE
PERMEATE

FIGURE 3.3.14 : TUBULAR REVERSE OSMOSIS (DESIGN WITH MEMBRANE EXTERNALLY SUPPORTED)

SOURCE: JOHNSTON & LIM, 1973

Process Applications [1]

Reverse osmosis is used successfully in the treatment of electroplating rinse waters, not only to meet effluent discharge standards, but also to recover concentrated metal solutions for reuse. A limited number of other full-scale uses can be found in the treatment of sulphite streams from the paper industry and in the food processing industry.

Use of RO for industrial waste treatment is growing rapidly. The application of reverse osmosis for the treatment of hazardous wastes should be carefully evaluated (pilot or bench-scale) because of the potential for the chemicals to react with the membranes, leading to deterioration and eventual destruction.

Economic Factors [1]

Capital costs range from about \$0.13-1.00/L per day of purified water output, depending on the volume of waste to be treated. Total operating costs are in the range of \$0-25-1.25/m^3.

Energy Requirements [1]

Energy requirements are of the order of 2.5 kWh/m^3 of product water.

Resource Recovery Potential

Recovery of materials from the concentrated reject stream and the possibility of reusing permeate waters are feasible and should be considered.

Environmental Factors

Ultimate disposal of the concentrate stream is neccesary if materials recovery is impractical. Hazardous components are not treated, but are only concentrated in the reject stream effluent.

Institutional Considerations

Reverse osmosis processes create no unusual institutional considerations besides the ultimate disposal of waste residues and the treatment of liquid effluents.

ULTRAFILTRATION

Process Description (Figure 3.3.15) [1]

There is no sharp distinction between reverse osmosis and ultrafiltration (UF). However, UF systems operate at pressures of only about 70 - 700 kPa. Separation of the solute from the solvent in ultrafiltration is based primarily on the size of the solute which, depending on the particular membrane porosity, can range from about 2 to 10,000 millimicrons.

Like RO, UF yields a permeate and a concentrate stream. Further treatment and/or disposal of these streams depends on each particular application.

Although early UF membranes were derived from cellulosic materials, modern UF membranes are made from a variety of noncellulosic synthetic polymers (e.g., nylon, polyvinylidene fluoride, polysulfone, etc.). As with reverse osmosis, early UF units were of the plate-and-frame type. However, assemblies in the form of scrolls, straight tubular and helical tubular are the most predominant in commercial applications today.

Factors affecting ultrafiltration performance include pH, temperature, fouling or scaling tendencies, presence of chlorine, concentration polarization and operating pressure. To prolong membrane life, streams containing strong oxidizing agents, solvents and other organics that can deteriorate the membrane should be given proper pretreatment or treated by other methods. Performance and membrane life of UF systems can be best established through onsite pilot plant investigations.

Waste Inputs [1]

Ultrafiltration is capable of treating dilute or concentrated aqueous waste streams containing one or more solute components. Appropriate for treatment of the following wastes (by UCD classification): 221-224; 251; 262; 454-455.

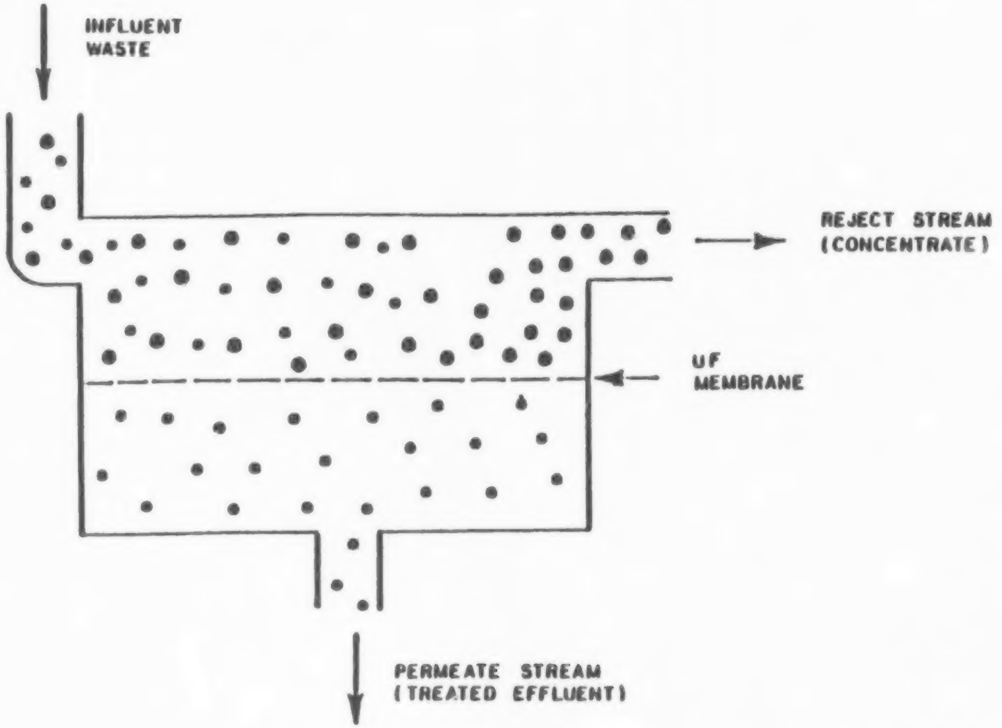

INFLUENT
WASTE
REJECT STREAM
(CONCENTRATE)
UF
MEMBRANE
PERMEATE STREAM
(TREATED EFFLUENT)

FIGURE 3.3.15. : SCHEMATIC DIAGRAM OF MEMBRANE ULTRAFILTRATION PROCESS

SOURCE: A.D. LITTLE, 1977

Effluent and Residuals [1]

Ultrafiltration produces two effluent streams, one is concentrated in the rejected (larger colloidal sized) solute while the permeate stream contains the retained solute.

Implementation, Reliability [1]

Ultrafiltration is a proven technology that has been successfully applied to both homogeneous solutions and to colloidal suspensions that are difficult to separate by other means. Commercial applications have been mainly with aqueous solutions. Ultrafiltration processes can be adapted to large scale applications of waste management.

Process Applications [1]

One of the earliest uses for ultrafiltration was the treatment of sewage. Current industrial applications include oil-emulsion waste treatment, electropaint recovery, and protein recovery from cheese and soy whey. There are also smaller (on the order of 38,000m^3 per day) plants for the treatment of textile sizing wastes and wash water from electronics component manufacturing, and for the production of sterile water for pharmaceutical manufacturing.

There are a number of other applications where ultrafiltration may become commercially significant within the next five years. These include: treatment of dye waste, pulp-mill waste, industrial laundry waste, and recovery of sugar from orange-juice pulp, products from pharmaceutical and fermentation industries, and purification of power plant boiler feedwater and water for beverages.

Economic Factors [1]

Capital and operating costs are dependent on the specific application and the capacity of the system. For large plants, capital costs may be \$0.25 - 1.00/L per day; operating costs may be \$1.25 -2.50 per m^3.

Energy Requirements [1]

Electrical energy for pumping to maintain flow at operating pressures may be as much as 30% of total direct operating costs.

Resource Recovery Potential [1]

The potential for resource recovery is favourable for both the concentrated waste stream and the ultrafiltered solution.

Environmental Factors [1]

Ultrafiltration residues are typically a concentrate of the undesirable or toxic components and usually require further processing unless valuable byproducts can be recovered.

Institutional Considerations

Ultrafiltration processes create no unusual institutional considerations besides the treatment of liquid effluents and the ultimate disposal of waste residuals.

STRIPPING

Process Description (Figure 3.3.16) [1]

Stripping represents a potential treatment process for the removal of volatile organics, hydrogen sulphide, and ammonia from aqueous special wastes streams. Furthermore, it can reduce high organic loads, sequester organic load variations and remove potentially toxic or inhibitory compounds, thus making the wastes more amenable to biological treatment. For steam stripping, it may be considered a form of fractional distillation. Steam or air can be used for stripping and is injected into the base of a distillation column and carries dilute volatile components with it. Two aqueous output streams result, one a concentrated solution of volatile organics and the other a dilute stream containing only residual traces of volatile organics.

Stripping is normally carried out as a continuous operation usually employing a packed tower for air stripping and a conventional fractional distillation column for steam stripping. Wastes enter the system near the top of the stripping column and flow by gravity countercurrent to the steam and organic vapors rising up from the bottom of the column. As the wastewater passes through the column, contact with the rising steam or air "strips" the volatile organics, progressively reducing organic concentrations until the wastewater is discharged from the bottom of the column.

Waste Inputs [1]

Stripping removes gases and volatile organics from dilute aqueous waste streams. The input wastewater contains dissolved gases or volatile organics. Appropriate for treatment of the following wastes (by UCD classification): 211-217; 221-223; 231-235; 233-239.

Effluent and Residuals [1]

Steam stripping produces two effluent liquid waste streams and also creates a potential air pollution problem. One effluent stream (product stream) carries treated wastewater containing small concentrations of contaminants. Depending on the waste characteristics, this stream may require further

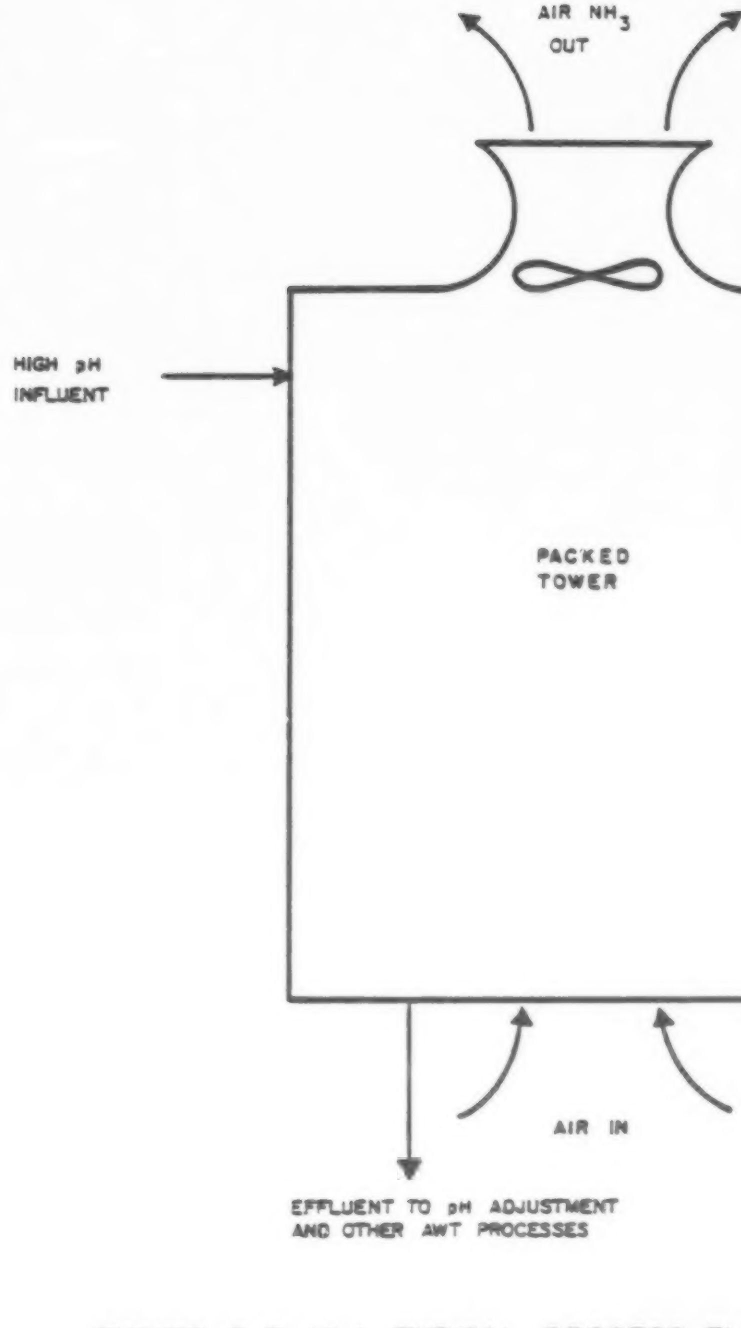

AIR NH_3
OUT
HIGH pH
INFLUENT
PACKED
TOWER
AIR IN
EFFLUENT TO pH ADJUSTMENT
AND OTHER AWT PROCESSES

FIGURE 3.3.16 : TYPICAL PROCESS FLOW SCHEMATIC – AMMONIA STRIPPING WITH AIR

SOURCE: E.J. STRUZESKI, 1978

treatment prior to discharge. The concentrated solution contains most of the stripped gases or volatile organics and may be handled for further treatment, ultimate disposal or recovery.

Air stripping generally produces one effluent liquid waste stream and a residual air emission. The liquid waste steam may require additional treatment (physical/chemical, or biological) prior to discharge. Depending on the waste characteristics, the air emission may require treatment using such systems as carbon adsorption prior to discharge.

Implementation, Reliability [1]

Stripping is a proven technology for the efficient removal of many volatile waste streams in aqueous solution. Both dilute and concentrated waste steams can be treated using steam or air stripping processes.

Process Applications [1]

Stripping has been used for many years to recover ammonia from coke oven gas. It is also used to recover sulfur as H_2S from refinery raw waste. Other applications include phenol recovery, vinyl chloride removal from PVC suspension resins, solvent recovery/removal, and removal of organics and sulfur from Kraft mill condensates. Toxic or refractory organics that have been successfully stripped from wastewaters include chlorinated hydrocarbon by-products and complex aldehydes.

Future applications of steam or air stripping look promising. Its use for waste treatment is growing. The most attractive applications are those that permit byproduct recovery, thus offsetting fairly high operating costs.

Economic Factors [1]

Capital investment for a new 750 L per minute single stage (one column) "sour water" steam stripper could range between $500,000 and $2,000,000 for stainless steel construction. Treatment costs of this system would be about

\$2.50-\$6.25/m^3. A capital investment of \$2-5,000,000 would be required for a two stage (two columns) 750 L per minute system for the recovery of NH_3 and H_2S.

Energy Requirements [1]

For steam stripping, the primary energy requirements are for steam. Steam requirements could range between 60 - 300 kg of steam per m^3 of waste.

Resource Recovery Potential [1]

The potential exists for the recovery of H_2S, NH_3, or other volatiles from the residual wastewater.

Environmental Factors [1]

Steam stripping replaces the air pollution potential posed by air stripping with a concentrated wastewater problem. The concentrated steam containing the bulk of the volatile organic components is processed for recovery or incinerated. If the incinerated steam contains sulphur, SO_2 emissions must be controlled. The environmental impact of discharging the treated dilute waste stream depends on the nature and the residual concentration of the remaining volatile organics in the wastewater. Air stripping generally requires further treatment of the air discharge, employing such systems as carbon adsorption.

Institutional Considerations

Stripping involves institutional concerns that include the treatment of liquid effluents and the potential problems of odours and noise.

SOLVENT EXTRACTION

Process Description

Liquid-liquid extraction, also often incorrectly referred to as solvent extractions, is a well established unit operation which makes use of differences in solubility and selectivity of a solute between different solvents. Long used in the chemical processing industry, solvent extraction has now also gained a firm foothold in wastewater treatment. One of its chief applications is the recovery of phenols and related compounds from petroleum refinery, coke oven and phenol resin plant wastewaters (see Figure 3.3.17). Another well known application of solvent extraction is the recovery of acetic acid. Due to the development of selective complexing agents in the 1960's, solvent extraction has also become an effective and economical method for reclaiming metals and cyanides from plating waste streams as well as metals from electroplating hydroxide sludges.

Basic steps involved in the solvent extraction of organic species from wastewaters include the transfer of the solute from the aqueous phase into the solvent, separation of the solvent from the solute, recycle of the solvent and recovery of solvent lost to the wastewater raffinate.

In the solvent extraction of metals, the wastewater stream is contacted with a solvent containing an organic reagent which combines preferentially with the metal, making it soluble in the organic phase. The aqueous and organic phases are then readily separated since they are immiscible. The extracted metal is stripped from the organic solvent with an acid and is concentrated in a water-soluble form, thus making it recoverable by such methods as electrowinning.

The solvent used may be a single chemical component or a solution containing several components. Benzene, kerosene and toluene are some of the more common solvents in usage; most commercially available solvents are custom-tailored proprietary formulations. Ideally, the solvent employed should be inexpensive, have a high distribution coefficient for the solute, and have a low solubility in water. Industrial solvent extraction contactors can be classified into several categories; e.g., simple gravity columns, mechanically agitated columns, mixer

SOURCE: MULLIGAN AND FOX, 1976

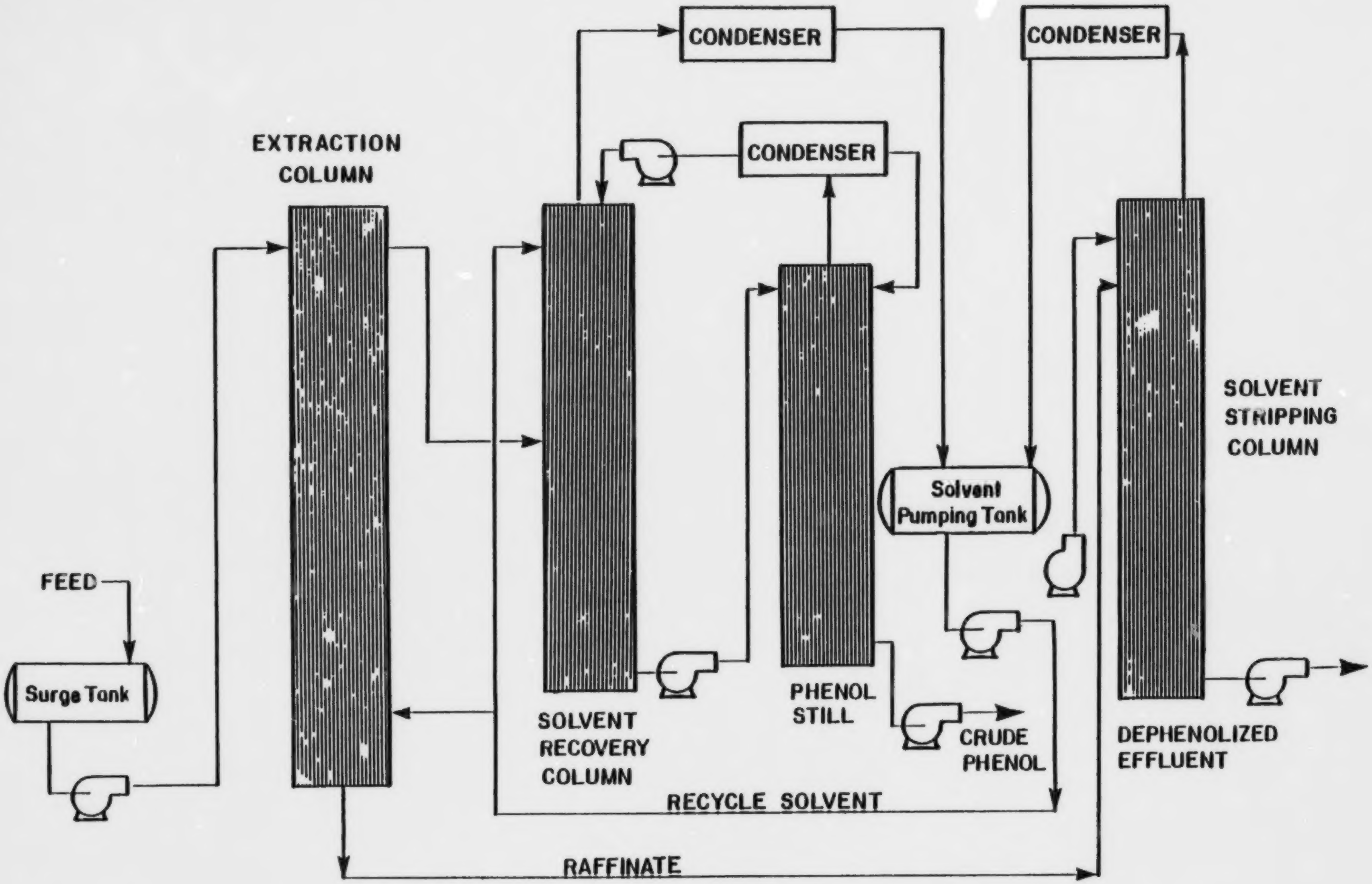

CONDENSER
CONDENSER
EXTRACTION COLUMN
CONDENSER
FEED
Surge Tank
SOLVENT RECOVERY COLUMN
PHENOL STILL
Solvent Pumping Tank
CRUDE PHENOL
SOLVENT STRIPPING COLUMN
DEPHENOLIZED EFFLUENT
RECYCLE SOLVENT
RAFFINATE

FIGURE 3.3.17 : SOLVENT EXTRACTION OF PHENOLS FROM COKE WASTE

settlers and centrifugal collectors. The counter-current multistage extractor is most widely used in industry. Selection of solvent and solvent rate are the most important factors in the design of solvent extraction systems.

Waste Inputs

Solvent extraction is very effective for the removal of phenols, acetic acid, cyanide and heavy metals. Appropriate for treatment of the following wastes (by UCD classification): 112, 131, 146, 213-217, 257, 431, 445.

Effluent and Residuals

Even though very high removal efficiencies (e.g., greater than 99%) of organic and inorganic compounds are attainable by employing appropriate solvents, in most cases solvent extraction alone cannot adequately reduce the concentration of toxic compounds to levels low enough to permit direct discharge of the treated effluents to surface waters. Furthermore, most of the complexing agents employed in the solvent extraction of metals are lethal to fish even at concentrations as low as 10 mg/L. Thus, some form of polishing treatment is necessary for the discharge stream after solvent extraction.

Implementation, Reliability

Solvent extraction is a proven technology for the separation and recovery of a multitude of organic and inorganic compounds. Steel mills and petroleum refineries have been practicing phenol recovery by solvent extraction for decades. Although commercial appliations of solvent extraction to metal recovery are fairly recent, several full-scale installations at plating plants have yielded positive results.

Process Applications

As mentioned, solvent extraction has long been used for the recovery of phenols from refinery, coke oven, coal-refining, etc. effluents. Leading dephenolization processes include the benzene-caustic, phenosolvan and Ifawol processes. Removal efficiencies of c. 98%. are readily attainable by these techniques.

High molecular weight amines, particularly quaternary amines, are highly efficient solvents for the removal of mercury from brine and other chloride systems where the mercury is present as the $Hg\ Cl_4^{-2}$ complex. The U.S. Bureau of Mines has reported the successful recovery of nickel and zinc from wastes arising from the phosphation of automobile bodies, yielding recoveries of 99%. for both metals. Recovery of zinc from various aqueous streams is possible through the Espindesa process, a two-stage solvent extraction technique developed by Tecnicas Reunidas of Spain. In Sweden four solvent extraction processes have been commercialized in recent years and two of them have been installed in large treatment plants to recover metals from various industrial wastes. For example, one of these, the so-called "MAR" process is suitable for recovering such metals as nickel, copper and zinc from electroplating hydroxide sludges.

Solvent extraction has also been successfully applied to the recovery of nitric and HF acid from stainless steel pickling solutions and may also be used for the treatment of oily wastewaters and for effluents containing biologically refractory organics.

Solvent extraction is particularly viable in situations where dilute solutions containing relatively low concentrations of valuable constituents are encountered. Consequently, in the coming years, solvent extraction will most likely be used as a recovery step applied to individual (or segregated) process waste streams.

Economic Factors

In conventional extraction processes, the principal operating costs are for energy and make-up solvent. Obviously, capital and operating costs can vary widely depending on a number of factors; e.g., the material being extracted, the efficiency of extraction, solvent losses, and the value of the recovered solute. For example, capital cost of a plant treating $379m^3$/day of phenol waste containing 5,000 mg/l of phenol and yielding 2,273 kg phenol per day was $400,000 while annual operating cots exclusive of solvent losses were $200,000. Credit for the recovered phenol was $100,000/yr.

Energy Requirements

In the recovery of organics by solvent extraction, the principal energy usage is steam for distillation. Steam requirement is highly dependent on the concentration of organics in the waste and the ease with which the solvent can be separated from the organic extract and the aqueous raffinate. Energy is also required for the operation of pumps, agitators, mixers and sundry other equipment.

Resource Recovery Potential

Recovery of solute as a saleable product, giving credit to the operation, is one of the main advantages of solvent extraction. As mentioned above, phenols, acetic acid, cyanide, heavy metals and a variety of other organics and inorganics may be readily recovered from industrial wastewater streams by solvent extraction.

Environmental Factors

As noted previously, solvent extraction cannot attain sufficiently high removal of toxic and hazardous waste constituents to permit direct discharge of the treated effluent to surface waters. Some form of polishing step (e.g., activated carbon adsorption) is a must if discharges from solvent extraction are to be released into streams or lakes. Moreover,some solvents (e.g., benzene) used are highly flammable in addition to posing a threat to the health of operating personnel and consequently, must be handled with care.

Institutional Considerations

There are no unusual institutional considerations involved in the treatment of wastewaters by solvent extraction.

ELECTROLYTIC PROCESSES

Process Description

Electrolytic techniques can be used for a variety of purposes in wastewater treatment, e.g., to plate out dissolved metals, to oxidize cyanides, or to convert trivalent chromium to hexavalent chromium. The method is most applicable to wastes containing high concentrations of cyanide and for solutions having high (i.e., more than 2 g/L) levels of metal. Moreover, electrolytic treatment is one of the most effective processes for destroying nickel, copper, ferro, and ferri cyanide complexes. Metal recovery from wastewaters using conventional electrolysis is rather impractical due to high power consumption; however, unique new cell designs developed within the past few years have brought about dramatic improvements, allowing the efficient and economical recovery of metals from even relatively dilute solutions. Included among these recent innovations are the Extended Surface Electrolysis (ESE) process from DuPont, the Fluidized Bed Electrolysis (FBE) process from Akzo Zout, the Swiss-Roll Cell designed at the Swiss Federal Institute of Technology, the carbon fibre reactor from HSA Reactors, the Chemelec unit developed by the Electricity Council Research Centre of Great Britain and the Eco-Cell system from Ecological Engineering Ltd. (see Figure 3.3.18)

The concepts behind conventional electrolytic recovery of metals are straight forward; a direct electric current is passed through the metal-bearing solution by means of cathode plates and insoluble anodes. As the current flows from the anode to the cathode, the positive metallic ions are attracted to the cathode plate and deposited there. Deposition continues as long as the current is present and sufficient electrolyte exists. Accumulated metal can be readily removed from the cathode by a variety of methods.

Novel cell designs operate on the same principle as conventional electrolysis systems; however, cathode and anode materials of construction and arrangements are substantially different. For example, DuPont's ESE process employs a so-called fluffy cathode and a thin sheet anode and the entire system is constructed like a sandwich. On the other hand, the Eco-Cell process employs a rotating cathode.

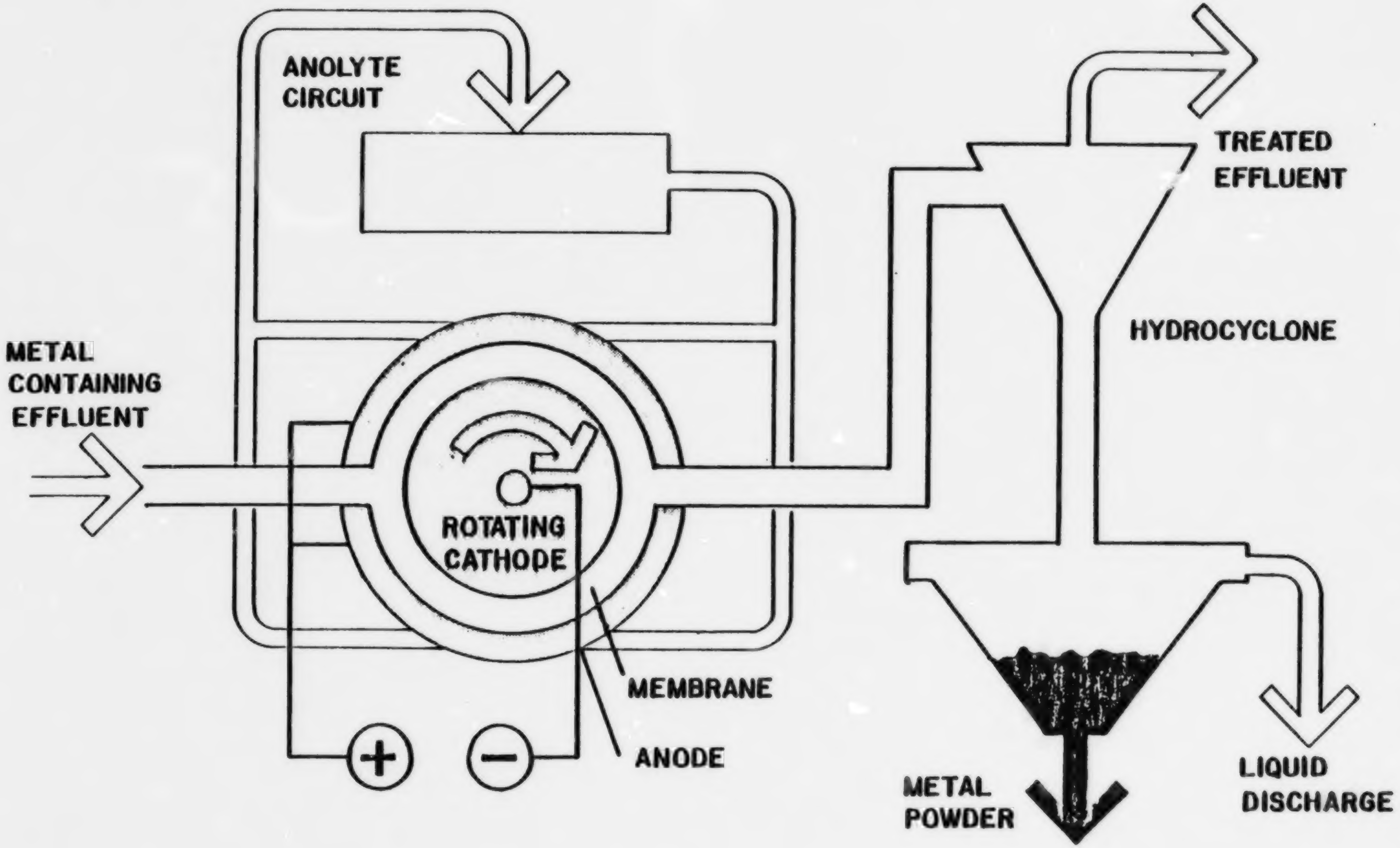

ANOLYTE
CIRCUIT
TREATED
EFFLUENT
HYDROCYCLONE
METAL
CONTAINING
EFFLUENT
ROTATING
CATHODE
MEMBRANE
ANODE
+
−
METAL
POWDER
LIQUID
DISCHARGE

FIGURE 3.3.18: ELECTROLYTIC RECOVERY

Waste Inputs

Electrolytic metal recovery is attractive for wastes orginating from a wide variety of industries, e.g., electroplaters, rolling mills, printed circuit board manufacturers, chemical processors and photoprocessors. Applicable to the following waste streams (by UCD classification): 111, 131, 141.

Effluent and Residuals

Quality of the discharge from electrolytic treatment systems depends on the characteristics of the influent wastewater stream and the efficiency of the treatment process. For example, low levels of residual cyanide can be attained by electrolytic decomposition provided sufficient reaction time is allowed. While advanced electrolytic cell designs can attain metal recoveries of 99%, simpler systems usually remove 90-95% of the metals.

Implementation, Reliability

Electrolytic techniques are proven treatment methods for metal recovery and cyanide destruction and are currently widely used in a multitude of industries; particularly metal finishing operations. While formerly restricted to the treatment of concentrated solutions, advances in cell designs have greatly broadened the applicability of electrolytic recovery processes and consequently their usage will most likely experience substantial growth in the near future.

Process Applications

As mentioned above, electroplaters, rolling mills, printed circuit board manufacturers and photoprocessors are some of the leading users of electrolytic recovery systems. Mercury from brine solutions as well as metallic catalysts from various chemical manufacturing waste streams can also be recovered by this technique. In the novel electrochemical regeneration system developed by General Motor Corp., spent chromic acid is recycled by reoxidizing trivalent chromium to the hexavalent form.

Applications of electrolytic processes to the treatment of mixed liquid industrial wastes are rather limited. For example, Central Industrial Detoxification Systems, Inc. of Nashville, TN, a waste disposal firm, has acquired a unit for its wastewater treatment facility from Eco-Cell of Great Britain a few years ago.

Economic Factors

Electrical power needed to provide the current is the major operation cost. Electrolytic treatment is not a labor-intensive process. Typical operating costs for treating plating wastes are about $15/1000 liters, excluding the value of the recovered metal. Capital costs of small package treatment plants having capacities of 1200-2500 liters/hr which are suitable for electroplaters are in the range of $20,000 - $25,000.

Energy Requirements

Electrical power to supply the current is the major energy requirement. Energy is also needed to operate pumps and other sundry equipment. Of course energy requirements in any given situation depends on a multitude of factors; e.g., the concentration of metals in the solution and the type of recovery process employed. For example, energy consumption by the Chemelec process is about 6000 - 10000 kWh/tonne of metal.

Resource Recovery

Ability to recover metals having a high resale value is one of the chief advantages of electrolytic techniques. As mentioned already, new cell designs are very efficient in recovering metals.

Environmental Factors

Treatment of wastewaters by electrolytic methods may not reduce heavy metal or cyanide concentrations to levels low enough to permit discharge. Should effluent quality fall short of discharge limits, additional treatment by other methods (e.g., chemical treatment) is necessary.

Institutional Considerations

There are no unusual institutional considerations involved in the operation of electrolytic treatment processes.

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3.4 THERMAL PROCESSING

INTRODUCTION

Thermal processing is defined as the treatment of hazardous waste in a device which uses elevated temperatures as the primary means to change the chemical, physical or biological character or composition of the hazardous waste.

A properly designed and operated thermal processing system generally has the following advantages:

- **volume reduction:** i.e., bulky solids with a high combustible content and liquid organic wastes;
- **detoxification:** i.e., burns combustible carcinogenic compounds, pathologically contaminated material, toxic organic compounds, and biologically active materials;
- **efficiency/reliability:** i.e., virtually complete total combustion of compounds to elemental gases (i.e., CO_2, H_2O, etc.);
- **energy recovery:** i.e., large quantities of combustion products are produced with a high Btu content; and
- **materials recovery:** i.e., the resulting ash (i.e., slag) has a high metal content, or other properties suitable for its reuse.

These advantages have justified the development and application of a variety of thermal processing systems of widely different complexity and function to meet waste and site specific applications.

The following disadvantages may be associated with thermal processing: [1]

- **Cost:** thermal processing is a high cost waste treatment step, both in initial investment and in operation.

- **Operation:** severity of the processing environment results in high maintenance requirements and close control of feeding of different wastes to maintain efficiency and reliability.

- **Staffing:** requires highly qualified supervisory, operating and maintenance staff.

- **Secondary Environmental Impacts:** depending on elemental composition of waste, thermal processing generates gases, such as sulphur dioxide, sulphur trioxide, hydrogen chloride, nitrogen oxides, particulates as fly ash (down to submicron particles), as flue gas emissions which must be properly controlled. Solid residues (i.e. slag or ash) must also be properly disposed of, either to land disposal or reuse. Waste waters from liquid type air pollution control systems; if used, are generally acid and contain dissolved and suspended solids which must be disposed of, either as waste water or as particulate from a wet/dry scrubber process.

These disadvantages have been, or are being, addressed through technology refinements and proper management of system design and operation. There are many existing cases of properly designed and managed thermal processing systems that effectively meet the needs of process and environmental requirements. Thus, thermal processing is functioning as an important viable concept in waste management.

A few thermal processing methods, such as incineration, are well-developed and well-understood technologies with proven operating facilities that meet both process and environmental requirements; others, such as plasma technology, are in various stages of development with laboratory scale test units or small experimental pilot units being used to obtain fundamental process, operating and environmental data.

Historically, incineration has been the preferred 'destructive' waste management process, and even today, it is the prime example of what is looked for in a thermal process suitable for waste management. In a typical incineration system, wastes and air are mixed in a refractory lined furnace where the organics are oxidized to hot combustion product gases that are discharged into the environment after removal of contaminants such as particulates. Such incineration systems served their purpose for the combustion of wood or similar refuse-type wastes. As additional types of wastes of greater chemical complexity were designated for incineration, the environmental effects required more sophisticated pollution control equipment to ensure cleaner stack emissions. For example, packed tower and venturi scrubbers, wet/dry scrubbers, etc. are now used for gaseous and solid particulate removal to achieve the very much greater removal of contaminant from the flue gases. Thus, a modern incineration system has become a complex chemical processing plant capable of a very wide range of waste combustion and reduction with minimal impact on the surrounding environment.

THERMAL PROCESSING TECHNOLOGIES

Available Technology

A wide variety of thermal processing technologies is available for application in waste management, but no single technology represents a system which can handle all waste materials under all conditions. Each technology has advantages and disadvantages that must be evaluated before selection. The selected technology must be matched with the specific waste application. The more appropriate thermal processing technologies are listed below with detailed technology evaluations following.

In addition to the general classes of thermal processing technologies described below, two approaches are not evaluated as specific technologies for application to waste management in the Province. These are pyrolysis and co-incineration which are not specific technologies, but rather represent thermal processing modes that can be applied to the other technologies. In co-incineration, hazardous wastes are mixed with other waste refuse or sludge to improve combustion characteristics. It is generally applicable to wastes with low energy values. In pyrolysis, wastes are heated in an oxygen deficient atmosphere (i.e., insufficient air for combustion to occur) to generate gases from the waste by pyrolytic reaction which can then be burned.

The general classes of thermal processing technologies currently applicable to waste management include:

- **Rotary Kiln:** Waste is burned in a rotating, refractory lined cylinder at temperatures ranging from 800 - 2000°C. Solid, liquid, gas or containerized wastes can be handled in a rotary kiln at a residence time ranging from seconds for gas and liquids to as much as an hour for the residue (i.e., slag or ash).

- **Calcination Kiln:** Waste is co-fired in a rotary kiln during the manufacture of cement at temperatures ranging from 1400 - 1700°C. This technology is suitable for many liquid organic wastes and is especially attractive for chlorinated wastes. A portion of contaminant that would normally leave with the flue gases are absorbed and chemically or physically bonded to the cement clinker. Residence time for wastes in the kiln varies from up to 10 seconds for the gas phase and minutes for the residue. The primary limitation is the effect of the waste on the final cement properties.

- **Evaporation:** Liquid wastes or sludges are heated at moderate temperatures within enclosed vessels to vaporize the liquid and separate the dissolved or suspended solids. This technology can generally handle organic or inorganic liquids, slurries and sludges containing solids. The separated products may then be separately treated or reused.

- **Liquid Incineration:** Wastes are atomized and burned in suspension at temperatures of 700 - 1700°C with a residence time of 0.1 to 2 seconds.

- **Fluidized Bed Incineration:** Waste is injected into or above an agitated bed of heated inert or chemically active particles where heat is efficiently transferred to the wastes during combustion at temperatures of 750 - 900°C. This technology is generally applicable to organic liquids, pastes, sludges, gases and granular or other processed solids that do not require very high temperatures for proper combustion.

- **Multiple Hearth Incineration:** Waste descends through several levels (hearths) where it is dried, raised to ignition temperature, then combusted within increasingly hotter combustion zones and then cooled in the lowest hearths. Volatile contaminant released in the upper hearths escape combustion unless recycled to the combustion hearths. This technology has been applied to sludges and granulated solid wastes where combustion temperatures of 750 - 900°C may be achieved.

- **At Sea Incineration/Shipboard Incineration:** Waste is burned, usually in a liquid-injection incinerator, on board a ship on the ocean. This approach is generally most applicable to liquid organic waste combustion achieving temperatures of 650 - 1700°C. Although this is not a unit thermal processing technology, it, like the calcination kiln, represents a successful use of technology in the U.S. and Europe for incineration of very hazardous waste with minimum impact on the environment.

- **Wet Air Oxidation:** Aqueous phase oxidation of dissolved or suspended organic substances at temperatures ranging from 175 - 350°C and pressures above the corresponding saturation pressure. Organic or inorganic aqueous wastes with high chemical oxygen demand (COD) may be considered for this technology. Residence times of up to an hour are possible in practice.

APPLICABILITY OF TECHNOLOGY TO WASTE MANAGEMENT

Based on a 1981 survey, there were 63 manufacturing companies in the United States and Canada engaged in the hazardous waste incinerator business.[2] Of these, 45 market only one type of incinerator system, and the remaining 12 market two or more types. Table 3.4.1 presents a listing of the hazardous waste incinerators in service by incinerator type and the number of companies. As the information in the table points out, the majority of hazardous waste incineration systems (over 60%) are the liquid injection type at the present time. This reflects the state of the hazardous waste management field in the United States prior to the adoption of the Resource Conservation and Recovery Act in 1980. Since the promulgation of these regulations, increased attention is being given to the use of thermal processing for hazardous and industrial wastes.

The incinerator market is dominated by a relatively small number of companies. Approximately 60% of the 342 operating hazardous waste incinerators were designed and constructed by six companies. Over 60% of the operating liquid injection units were produced by two companies. Of the 63 companies marketing hazardous waste incinerators, 28 have sold no units in the United States.

Hazardous waste incineration units vary markedly in size. The largest hazardous waste incinerator built was rated at 150 GJ/h. Facilities as large as 300 GJ/h are currently being considered by some industries. Several are considering incorporation of liquid injection or rotary kiln incinerators, or a combination of both, feeding into a common afterburner.

Other technologies, such as wet air oxidation, molten salt incineration and plasma reactors, are supplied by a handful of companies. Development work for these new and emerging technologies is mostly supported by government grants. However, some private venture capital may be available for funding several technology development programs.

TABLE 3.4.1

CURRENTLY OPERATING HAZARDOUS WASTE INCINERATORS [2]

Incinerator Type	Number of Companies Offering	Approximate Number of Hazardous Waste Incinerators in Service(1)	Percentage of Total
Liquid Injection	23	219	64%
Rotary Kiln	17	42	12%
Fluidized Bed	9	9	3%
Miscellaneous	24	72	21%
TOTAL	63	342	100%

(1) Built since 1969.

Concern has been expressed by many environmentalists about the potential environmental effects of thermal processing. The thermal processing of waste materials produces air emissions, ash, and, in some systems, liquid waste from liquid type air pollution scrubbing systems. All of these must be properly controlled. Control techniques for each are summarized in the following paragraphs.

- **Air Emissions:** There are basically three types of air emissions from a thermal waste processing system:

  - particulate matter
  - combustion products
  - uncombusted organic matter.

  Particulate matter consists of particles of inorganics and ash which range in size from less than a micron (a human hair is about 100 microns thick) to the size of a large grain of sand. Particulate matter is of concern when burning solid wastes and liquid wastes containing inorganic compounds such as metallics. Particulate matter itself is not typically considered hazardous, but because it has been recognized as a lung irritant and as a possible carrier for uncombusted organics, it is regulated by environmental regulatory agencies.

Combustion products include water vapour, carbon dioxide, nitrogen and sulphur oxides, metallic and non-metallic oxides, and acids depending upon the make-up of the waste being incinerated. Some carbon monoxide is also produced. In a properly operated system, however, the carbon monoxide is almost entirely converted into carbon dioxide.

Water and carbon dioxide are not typically considered pollutants. Nitrogen oxides and sulphur dioxide are presently regulated. While waste incineration is not a significant source of either of these two gases compared to fossil fuel boilers and automobiles, the emissions must still stay within regulations. Sulphur dioxide is normally controlled by scrubbing the off-gas in a caustic scrubber which can be accomplished with existing scrubber technology. Nitrogen oxides, which contribute to photochemical smog, are not as easily controlled as sulphur dioxide. The high temperatures necessary for destroying some hard-to-burn wastes have the side effect of converting the nitrogen in the combustion air into oxides. Nitrogen oxide formation in other sources such as coal fuel boilers is usually controlled by varying combustion conditions. This variation is usually not possible in hazardous waste incineration. This problem is under investigation by various researchers.[3] Hydrogen chloride gas, produced from the combustion of chlorinated wastes,[4] must be controlled for environmental reasons and to prevent corrosion to scrubber facilities. Such control is possible through the use of caustic scrubbers of either the wet or wet/dry type.

The emission of uncombusted or partially combusted organic matter must be at a minimum because many organic chemicals are either known or suspected carcinogens. Thus, the incineration of material must be complete. High destruction efficiencies are obtained by maintaining proper combustion conditions.[5] These conditions may require an afterburner, or secondary combustion chamber. Although it is very difficult to measure high level destruction efficiencies for low concentrations of contaminants, destruction efficiencies of 99.98% and better have been obtained in several types of facilities.

- **Ash:** Although ash from incinerators and their particulate matter control devices should not contain organic contaminants, it may contain various salts, metals and other trace non-combustibles and must receive proper disposal.

- **Liquid Effluents:** Thermal processing using wet scrubbing systems for gas clean-up and water for ash quenching produce a liquid effluent which is generally acidic or alkaline and may contain high concentrations of salts or other inorganics. These liquid effluents must be properly treated and disposed or discharged. The technology for achieving such treatment is usually incorporated as an integral part of hazardous waste treatment facilities.

Existing control techniques are capable of adequately controlling emissions generated from the thermal processing of most wastes.

ROTARY KILN

Process Description

The rotary kiln incinerator is a cylindrical refractory-lined shell mounted with its axis at a slight slope from the horizontal. It can be fueled by natural gas, oil or waste oil, or pulverized coal.

The basic system consists of the rotary kiln and a secondary combustion chamber. Solid wastes, sludges, waste drums, and liquid wastes can be fed into the rotary kiln. As these wastes move through the kiln, organic matter is burned. Liquid and gaseous wastes and purchased fuels are used as auxiliary fuel in both the kiln and the secondary chamber.

If the solid wastes contain excessive entrained liquid, a drying section can be incorporated into the system, usually in front of the rotary kiln. In the drying section, water and volatile organics are vaporized. These vaporized materials bypass the rotary kiln and are fed into the secondary combustion chamber. Liquid and gaseous wastes can be introduced into the kiln or the secondary combustion chamber.

The secondary chamber is used to achieve complete combustion of volatile organics and organics carried by gas-borne particles. Liquid wastes are atomized and burned in suspension. If high energy content combustible waste liquids are not available, purchased fuels are required.

Waste Inputs

Rotary kilns (Figure 3.4.1) are a very versatile type of thermal process system. They are capable of handling slurries, sludges, bulk solids of varying size, containerized wastes, combustible and noncombustible liquid wastes. This technology has been successfully used for thermal processing of the following wastes (UCD classification): 211-217; 221-228; 241-245; 248; 251; 254; 261-264; 281-289; 446; 454-455; 512-513; 521; 523; 528; 531-532.

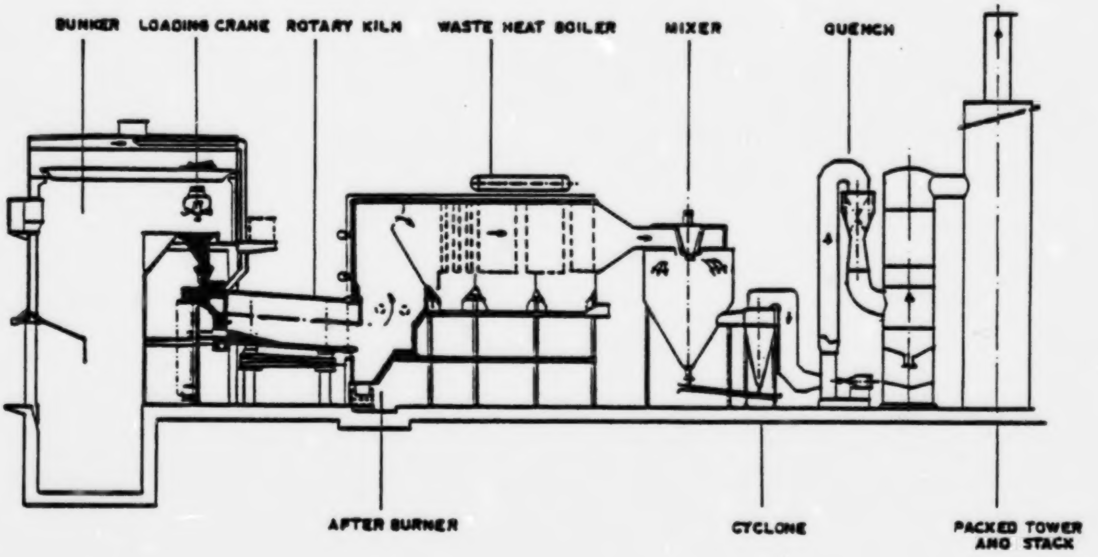
BUNKER
LOADING CRANE
ROTARY KILN
WASTE HEAT BOILER
MIXER
QUENCH
AFTER BURNER
CYCLONE
PACKED TOWER AND STACK

FIGURE 3.4.1

EXAMPLE OF MODERN HAZARDOUS WASTE ROTARY KILN INCINERATOR WITH WASTE HEAT RECOVERY AND HIGH EFFICIENCY WET/DRY FLUE GAS SCRUBBER (BIEBESHEIM, WEST GERMANY). (REPRODUCED COURTESY OF VON ROLL A.G.).

Effluent and Residuals

The rotary kiln system produces two or three effluent waste streams. Liquid and gaseous effluent streams are related to the air pollution control system incorporated to treat air emissions. Wet scrubbing systems may produce a relatively concentrated liquid effluent that requires treatment, or they may incorporate a recirculation and drying feature that eliminates the liquid stream (i.e., contaminates are then removed as dry particulate). The gaseous effluent stream after being treated by the air pollution control system is discharged by means of a stack. The solid inorganic residues comprise the third effluent stream which are made up primarily of slag particulates and other nonburnables and scrubber dry particulate which require ultimate disposal, generally to a land disposal facility.

Implementation, Reliability

Rotary kiln incinerators are a well-proven technology currently applicable to the ultimate disposal of many forms of combustible waste material. At the present time, rotary kilns represent a major incinerator type being used for wastes disposal, either for individual industrial plants, or as a regional central disposal facility.

Regularly scheduled preventive maintenance of kiln refractory and the scrubber systems is vital to long-term consistent high destruction efficiency of wastes. In addition, the mix of wastes fed to the rotary kiln must be carefully controlled (as for any thermal process) to prevent undesirable thermal chemical reactions in the combustion process that also affect slag or ash properties and thus inhibit destruction of the waste or flue gas scrubbing efficiency.

Process Applications [7]

Rotary kiln incinerators are applicable to many organic wastes, or organic wastes containing phosphorus, silicon, sodium, sulphur, halogens (fluorine, chlorine, bromine, iodine).

Rotary kiln incinerators are currently used to incinerate such wastes as:[7] PCBs in capacitors, nitrochlorobenzene tars, TDI reactor tar bottoms, obsolete munitions, obsolete chemical warfare agents (GB, VX, and mustard gas), diphenylamine reactor tar bottoms, acrylonitrile manufacturing wastes, acrylonitrile reactor tar bottoms, alkylated phenol steam still bottoms, phenylamine tar wastes, phenolic tar from 2, 4-D manufacture, epichlorohydrin manufacturing wastes, chlorotoluene production wastes, catch basin grease, nitrite pitch from production of surface active agents.

Economic Factors

Capital costs for a rotary kiln incinerator facility are highly dependent upon the waste quantity, type of waste, and the necessary pollution control system to meet environmental needs at the facility.

Maintenance costs are high for these facilities on a dollar basis, but on a per unit weight of waste treated are quite low provided a reasonably high level of utilization of the equipment is maintained.

Energy costs are highly dependent on the calorific value of the waste, percent water in the waste, and available wastes to offset purchased fuel that might be required for some waste treated. These costs are very dependent upon the managerial control of scheduling various wastes to the kiln to minimize purchased energy requirements while insuring that the mix of chemicals will not result in final combustion products that may affect slag properties, ash properties, or cause deposits in waste heat boilers or scrubbing systems affecting their performance.

Energy Requirements

Energy requirements are highly dependent on the calorific value of the waste to be destroyed and the availability of waste fuels. Proper management of scheduling will reduce energy requirements to a minimum.

Resource Recovery Potential

Ash discharge from the kiln usually has a high concentration of metal oxides which may be suitable for recovery of metals, or reuse as are inert material (depending upon contaminants in the original waste). Metal recovery or ash reuse can only be effected if the ash is collected on a "batch" type process so that they are identified against the actual waste and their original chemical compositions fed to the kiln. Analysis of the ash would be required in initial reuse applications and related to the original waste materials permitting later large-scale reuse under a controlled management waste destruction schedule.

Residual energy in the hot flue gas products may be recovered in waste heat boilers as steam or hot water for use throughout the facility for heating or combustion air preheat purposes. Many modern facilities already incorporate waste heat recovery boilers and combustion air preheaters.

Environmental Factors

Rotary kiln incinerators are a well-proven technology with many operating plants throughout the world for treatment of hazardous combustible waste. The environmental factors relate specifically to the resulting ash of the destroyed waste, liquid discharge from wet scrubber systems, if employed, particulate removed from the flue gas stream and flue gas emissions to the atmosphere.

Ash disposal will be to secure landfill sites for that ash that is not suitable for reuse; to normal landfill sites for inert ash; to metal recovery or reuse in other forms where warranted.

Latest technology for flue gas scrubbing results in minimum liquid waste to be treated (or no liquid waste at all) leaving particulate to be disposed of in the same manner as kiln ash. Emissions to the atmosphere are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many rotary kiln incinerators as latest state-of-the-art incineration technology when coupled with appropriate air pollution control systems.

MULTIPLE HEARTH INCINERATOR

Process Description

The multiple hearth incinerator (Figure 3.4.2) has been utilized to incinerate sewage sludges, tars, granulated solids, and some liquid and gaseous combustible wastes. Normally, waste material enters the furnace by dropping through a feed port located in the furnace top. Rabble arms, attached to a centre shaft, rotate to spiral the waste across the face of the hearth to drop holes. The waste drops from hearth to hearth through alternating drop holes located either along the periphery of the hearth or adjacent to the central shaft. Ultimately, the ash falls to the furnace floor. Air and combustion products normally flow countercurrent to the feed waste (from the bottom to the top of the incinerator).

The rabble arms located at each hearth level all rotate in the same direction; additional agitation of the waste (back rabbling) is accomplished by reversing the angles of some of the rabble teeth. Waste retention time is controlled by the design of the rabble tooth pattern and the rotational speed of the central shaft.

Some liquid and gaseous combustible wastes may be injected into the unit through auxiliary burner nozzles.

Waste as it drops through the multiple hearth incinerator is first dried in the upper hearths where some volatile matter may be driven off and due to the lower temperatures in this area may not be properly burned (unless an afterburner section is employed firing suitable fuels). The normal temperatures of the central hearths where combustion takes place is in the order of 900-1000°C. In the lowest hearth, the resulting ash emanating from the combustion hearths is cooled by the upsweep of combustion air from the bottom hearths.

Waste Inputs

Multiple hearth incinerators can be used to dispose of some sludges, tars, and granulated solid wastes. Liquid and gaseous wastes can be used as auxiliary fuel in the burners or injected for incineration depending upon their calorific value and chemical compositions.

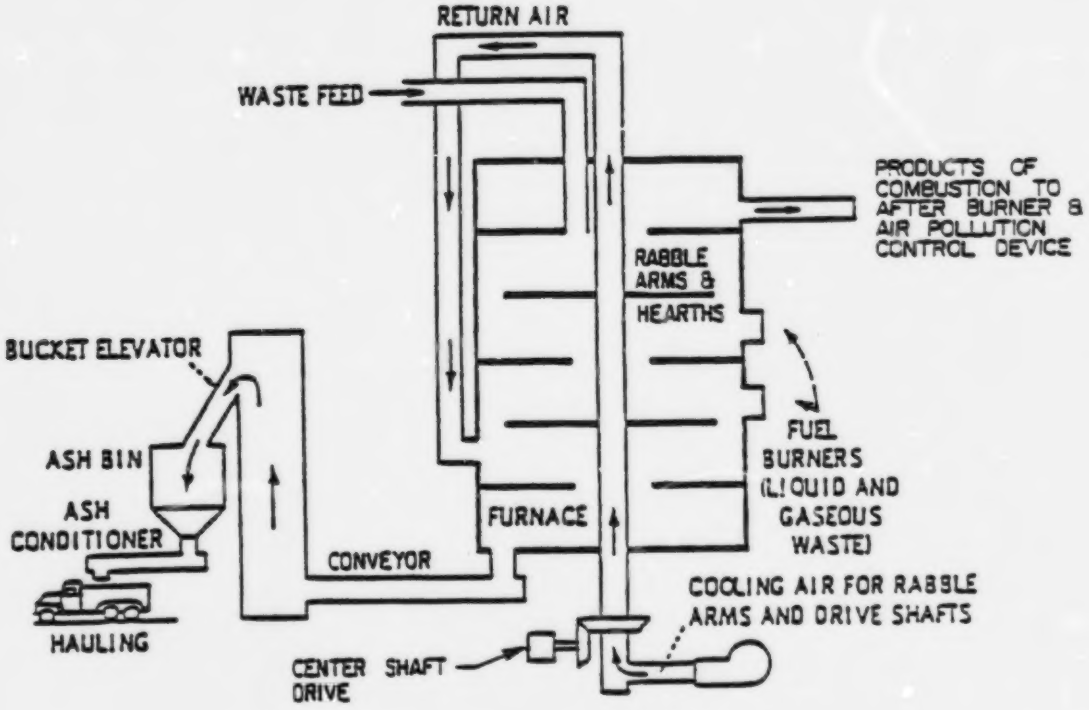
RETURN AIR
WASTE FEED
PRODUCTS OF COMBUSTION TO AFTER BURNER & AIR POLLUTION CONTROL DEVICE
RABBLE ARMS & HEARTHS
BUCKET ELEVATOR
ASH BIN
ASH CONDITIONER
HAULING
CONVEYOR
FURNACE
FUEL BURNERS (LIQUID AND GASEOUS WASTE)
COOLING AIR FOR RABBLE ARMS AND DRIVE SHAFTS
CENTER SHAFT DRIVE

FIGURE 3.4.2 : MULTIPLE HEARTH INCINERATION SYSTEM

SOURCE: BONNER ET AL., 1980

Temperatures achieved in combustion hearths are generally not high enough for the destruction of many hazardous wastes (especially chlorinated organics, etc.). Further, available residence time at maximum temperatures is quite short. Appropriate for treatment if the following wastes (by UCD classification): 245; 247-248; 252; 254; 258; 261-264; 281-286; 455; 513; 528; 531-532.

Effluent and Residuals

The multiple hearth incinerator produces two or three effluent waste streams. Liquid and gaseous effluent streams are related to the air pollution control system incorporated to treat air emissions. Wet scrubbing systems may produce a relatively concentrated liquid effluent that requires treatment, or they may incorporate a recirculation and drying feature that eliminates the liquid stream (i.e., contaminants are then removed as dry particulate). The gaseous effluent stream after being treated by the air pollution control system is discharged by means of a stack. The solid inorganic residuals comprise the third effluent stream which are made up primarily of slag particulates and other nonburnables and scrubber dry particulate which require ultimate disposal, generally to a land disposal facility.

Implementation, Reliability

The multiple hearth incinerator has moderate application to waste management. In general, multiple hearths are not suited for wastes containing fusible ash, those which require extremely high combustion temperatures, irregular bulky solids or waste in metal, plastic or similar containers (regardless of size). Multiple hearth incinerators are very susceptible to thermal shock resulting from frequent feed interruptions or large variations of amounts of water in the waste. These conditions can lead to early refractory or rabble arm failures and can make temperature control difficult. When the multiple hearth is applied to thermal oxidation of waste streams, a secondary combustion chamber will be necessary to incinerate unburned contaminants in the combustion gases.

The materials of construction of rabble arms and the central shaft must be suitable for the chemical composition of the waste fed to the unit to resist corrosion effects from reducing atmospheres (i.e., oxygen deficient) that may occur in the combustion zone. These conditions, in general, arise from the fact that the waste material is ploughed with combustion air passing above the material which ma, result in a localized reducing atmosphere as the waste material ignites and burns.

Process Applications [7]

Multiple hearth incinerators have been used since the 1930's to incinerate municipal sewage sludge and various similar industrial sludges. In waste management, they have been used to incinerate still bottoms, solid residue from manufacture of aromatic amines, reactor bottoms from PVC manufacture, some chemical sludge, oil refinery sludge, and pharmaceutical waste. They also have been used for carbon regeneration and preparation of similar waste material for reuse.

Economic Factors

Capital costs for a multiple hearth incineration system capable of handling waste streams are high being very dependent upon the type of waste to be burned.

Maintenance requirements are high because of the many internal rabble arms and other portions of the equipment subjected to high temperature combusion conditions. The placing of such metal parts in direct contact with combustion products, especially under reducing atmosphere conditions, has not been evaluated with respect to the shortened operating life and maintenance requirements for such parts.

Operating costs for a multiple hearth incineration system will be highly dependent upon the waste to be burned and the availability of suitable waste gases and liquids of high calorific value that may be required to supplant purchased fuels.

Energy Requirements

Energy requirements are highly dependent on the calorific value of the waste to be destroyed and the availability of waste fuels. Proper management of scheduling will reduce energy requirements to a minimum.

Resource Recovery Potential

Ash discharged from a multiple hearth incinerator usually has a high concentration of metal oxides which may be suitable for recovery of metals, or reuse as an inert material (dependent upon contaminants in the originating waste). Metal recovery or ash reuse can only be effected if the ash is collected on a "batch" type basis so that they may be identified against the actual waste and the original chemical compositions fed to the incinerator. Analysis of the ash would be required in initial reuse applications and related to the original waste materials permitting later large-scale reuse under a controlled management waste incineration schedule.

Environmental Factors

Multiple hearth incinerator facilities have seen limited use for waste management being very dependent upon the types of waste to be disposed of. In general, they have been employed for the disposal of "low strength" and "low toxicity" sludges and granular material wastes.

The basic combustion process and combustion products path through the multiple hearth incinerator, depending upon the type of waste and its moisture content, may not lend itself to the total combustion of specific chemical compounds or their initial combusion products without the inclusion of a high-temperature afterburner section.

Ash disposal will be to secure landfill sites for ash that is not suitable for reuse; to municipal solid waste landfill sites for inert ash; to metal recovery or reuse in other forms where warranted.

Use of latest technology for flue gas scrubbing would result in minimum liquid waste requiring treatment (or no liquid waste at all) leaving particulate to be disposed of in the same manner as incinerator ash. Emissions to the atmosphere are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many multiple hearth incinerators as latest state-of-the-art incineration technology for specific "low toxicity" wastes when coupled with appropriate air pollution control systems.

EVAPORATION

Process Description[7]

Evaporation is a well-defined and firmly established physical process used in industry (Figure 3.4.3). It is applicable to liquids, slurries and sludges which contain suspended or dissolved solids, or liquids which are virtually non-volatile. The process is usually conducted in conventional mechanical evaporators such as multi-effect, vapor compression, multi-flash systems or direct evaporative or indirect evaporative dryers all of which use supplemental heat.

Evaporation is the vaporization of a liquid from a solution or slurry for separation of a liquid from a dissolved or suspended solid. The term "evaporation" should only be applied to a unit operation in which heat energy is transferred to a solution or suspension of a solid or liquid and where one of the components is not highly volatile.

Three general evaporation system classes are:

- **Natural Evaporators:** evaporation is induced by natural phenomena, such as solar energy or diffusion.
- **Direct Contact Evaporators:** evaporation where the heating medium is in contact with the liquid.
- **Indirect Evaporators:** evaporation using conductance of heat through physical barriers separating the liquid.

Waste Inputs[7]

Evaporation is being used currently for concentrating wastes such as sludges and plating and paint solvent waste, among many other applications. It is capable of handling liquids, slurries and sometimes sludges, both organic and inorganic, containing suspended or dissolved solids or liquids. Appropriate for treatment of the following wastes (by UCD classification): 111-112; 146-147; 211-221.

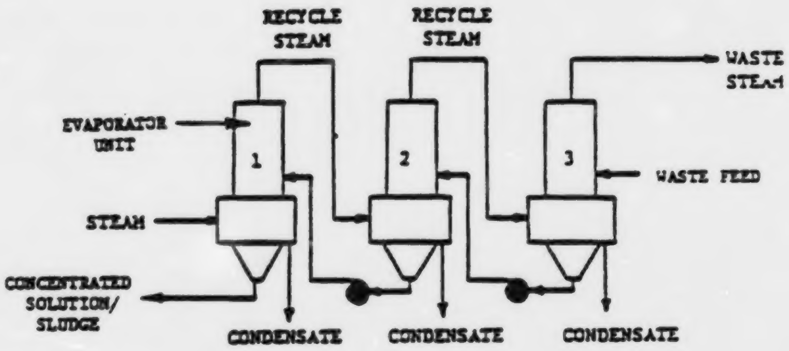
RECYCLE STEAM
RECYCLE STEAM
WASTE STEAM
EVAPORATOR UNIT
1
2
3
WASTE FEED
STEAM
CONCENTRATED SOLUTION/ SLUDGE
CONDENSATE
CONDENSATE
CONDENSATE

FIGURE 3.4.3: MULTIPLE STAGE EVAPORATION SYSTEM

SOURCE: A.D. LITTLE, 1977

Effluent and Residuals [7]

Evaporation produces a liquid (condensate) or gaseous effluent stream and a sludge residue. The liquid evaporated from the waste can be discharged either in a liquid form as a condensate or in a vapour form. The discharged effluent streams may require further treatment if the waste contains volatile organics or other contaminants. The waste volume is reduced, but the sludge residue requires ultimate disposal.

Implementation, Reliability

Evaporation is a proven technology for concentrating many liquids and separating liquids from solids. The equipment, in some instances, has withstood many decades of proven operating reliability, and shown itself capable of consistent results.

Process Applications [7]

Evaporation has application to many waste streams and can be used as a single technology for complete drying or concentrating of liquid waste streams and sludges, as a pretreatment step for volume reduction, or as a polishing treatment step prior to effluent discharge. Evaporation has been used as a thermal processing technology for the concentration of radioactive wastes and TNG; as a polishing step for spent molasses mash, dyestuff wastes, radioactive sludges, drying of sewage sludges for use as a fuel or soil conditioner; etc.

Economic Factors [7]

Evaporation may represent an economically viable waste processing technology, especially when waste heat is available, that permits concentration of liquid wastes which can then be further processed in another thermal process or other physical chemical process.

Capital costs are dependent upon the type and quantity of waste to be evaporated, its toxic nature and volatility. For the higher volatility and more toxic wastes the evaporator is normally incorporated with another process in order to achieve a better feed stock to the latter process or to reduce the operating costs or operating technical problems.

Maintenance costs are usually low, both on an absolute basis and on a per unit throughput basis.

Operating costs are highly dependent upon the availability of waste heat or waste type fuels suitable for the process application. Where purchased fuels must be used for supplying energy to the evaporation process, the operating costs are significantly higher.

Energy Requirements[7]

Energy requirements for evaporation vary directly with the process operating parameters, equipment heat transfer characteristics, liquid to be evaporated and the normal operating range for evaporation temperatures relative to the waste characteristics. Typically, the energy required is equal to the latent heat of evaporation of the liquid to be evaporated plus the nominal heat losses from the system.

Resource Recovery Potential

The volume reduction associated with evaporation enhances recovery potentials. If relatively pure solids are dissolved in the waste stream, these solids will be concentrated in the sludge or dried product and may be recovered. The evaporated liquid can be recovered in the condensate stream for reuse or futher treatment.

Resource recovery potential is high where the solid matter in a waste slurry or sludge has potential for reuse in the form of feedstock to an industrial process, feedstock for animals for food processing wastes, land application as soil conditioner (from sewage sludges), etc. In some countries these products are presently being recovered and reused.

Environmental Factors[7]

When the solvent being evaporated contains water, there are generally few pollution problems associated with evaporation vapours. Evaporation in such cases is only a volume reduction step, and ultimate disposal of the solid waste residue remains to be accomplished. In instances where evaporation liquors contain organics or other contaminants, they are generally condensed and will require further treatment for ultimate disposal.

Evaporation processes treating wastes that are both toxic and highly volatile produce off gases, liquors, and solid residue that require further treatment by other processes.

CALCINATION/CEMENT KILN

Process Description [7]

Calcination, a thermal process that makes use of an existing cement kiln, is generally applied to the incineration of aqueous liquids and sludges requiring elevated temperatures.

There are three basic types of calcination units; open hearth, rotary kiln and fluidized bed. Illustrated in the flow diagram (Figure 3.4.4) is a typical rotary kiln type cement calcination unit. Feed is introduced at the cool end of the kiln at the point where the gases and vapors are emitted. A high degree of turbulence, agitation and surface-to-gas contact is achieved with the inclination of the cement kiln. The partially calcined material travels slowly down the kiln while being exposed to increasing temperatures and is finally discharged at the end nearest the heat source. Feed addition and product removal are continuous. Kiln temperatures are generally in the 800-2000°C range. The off-gas residence time in the high temperature zone is 15-20 seconds.

Waste Inputs [7]

Cement kilns can be used to incinerate limited quantities of certain aqueous solutions, slurries, and sludges with the objective of chemically reacting some of the gaseous pollutants and the ash from the waste into the cement clinker. Tests have been performed on some units with PCB wastes in which the cement clinker absorbs, through chemical reaction, most of the remaining PCBs after combusting the waste as part of the fuel source. Waste input is limited to the impact it has upon the properties of the ultimate product (i.e., cement clinker). Waste should be limited to those forms, types and quantities that are well within the production capacity of cement kilns. This technology is generally appropriate for thermal processing of the following wastes (UCD Classification): 214-216; 225; 227; 241; 281.

Other calcine kilns for recalcination of lime or other products may be used in a similar fashion as noted for cement kilns. Again, the use is restricted to the end product being produced, as the waste to be disposed of must not affect the end product properties.

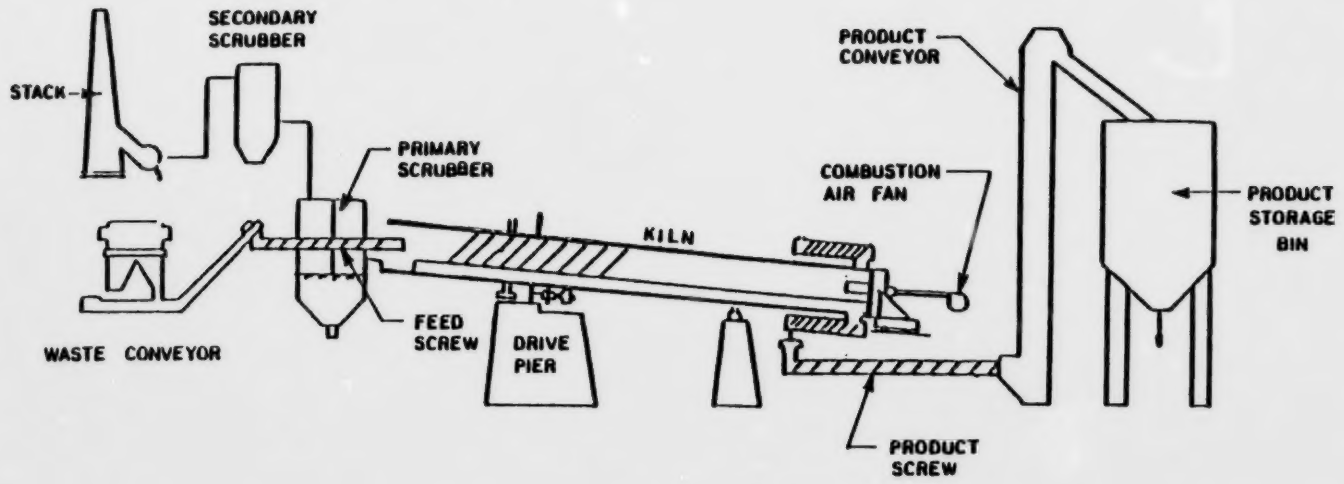
SECONDARY SCRUBBER
STACK
PRIMARY SCRUBBER
WASTE CONVEYOR
FEED SCREW
DRIVE PIER
KILN
COMBUSTION AIR FAN
PRODUCT CONVEYOR
PRODUCT STORAGE BIN
PRODUCT SCREW

FIGURE 3.4.4 : ROTARY KILN CALCINER

SOURCE: A.D. LITTLE, 1977

In certain instances, the calcination/cement kiln concept can be used where the end product is not for sale but would be placed in a appropriate landfill site. In such a case, a higher quantity of waste can be disposed of in the kilns.

Effluent and Residuals [7]

Calcination systems require extensive air pollution control equipment similar to that required for rotary kilns, as previously described. Additional pollution control may be required if waste is introduced at the cool end of the kiln and some of the combustion products and volatilized compounds cannot be fully reacted at the temperatures and residence time available at that end of the kiln. Waste should be restricted to that which will fit within the temperature and residence time limits of the kiln.

In most cases, where the waste combustion products are absorbed by the end product of the kiln, the resulting product is generally very stable for use in its original purpose or for storage or land disposal. Tests have indicated that some wastes, when introduced to cement kilns, have no impact upon the end product properties and result in virtually 100% destruction of the waste.

Implementation, Reliability [7]

There has been test work to study the applicability of cement kilns for hazardous waste disposal. Cement kilns are a potential thermal process system for waste management because of the high temperatures, relatively long residence time, and the chemical reactions of the ash and some of the waste products of combustion with the cement clinker.

Calcination is a well established process with many industrial waste treatment applications. It is a versatile one-step process which can be utilized for controlled types and quantities of wastes. Existing cement kilns can be utilized with little modification for waste processing.

Process Applications [7]

Calcination processes have been used in the recalcination of lime sludges from water treatment plants; coking of heavy residues and tars from petroleum refining operations, concentration and volume reduction of liquid radioactive wastes, and treatment of mixed refinery sludges.

Combustible wastes have been burned in commercial cement kilns as auxiliary fuel. The burning conditions within the kilns are generally suitable, based on temperature and residence time, to destroy combustible hazardous and toxic wastes. Although burning conditions within the kiln are usually adequate to destroy hazardous materials, industry may be concerned about quality control in the waste and its impact on the end product reliability. Of particular concern is the chloride content of waste. Cement kiln operations presently limit the chloride content of the waste to less than 2% by weight.

Economic Factors[7]

Adapting existing cement kilns to waste management represents a potential cost effective treatment approach. Capital investment would be necessary for upgrading existing facilities to improve materials handling and air pollution control. To build a new facility for waste disposal only, the capital and operating costs will be sensitive to the concentration of the material to be calcined and the waste materials being treated.

Maintenance costs will approach those for existing cement kilns or other calcine projects in industry where the intent is to build a separate waste facility utilizing these processes. Maintenance costs will be substantially less where existing cement kilns and calcine operations are utilized for disposal of limited quantities of specific wastes. The maintenance costs relative to the latter possibility will be greater than present industry maintenance costs by that amount required for the upgraded facilities, waste material handling and air pollution control.

Operating costs will vary little from existing industry costs for a separate waste facility. Operating costs at existing cement kilns or calcine plants will be essentially the same as for their present operation (i.e., a NIL value for the operating costs relative to the waste portion of the operation) plus the additional manpower for receiving and handling of the waste material to be disposed of.

Energy Requirements[7]

Energy requirements will be highly dependent upon the water and organic content of the waste streams. Where the facility is added to an existing industrial process, the limitations imposed upon the waste stream will include the need for high calorific value waste to eliminate purchasing additional fuel. Where the waste facility is to be a "stand-alone" facility it would be necessary to balance high calorific wastes, lower calorific wastes, and wastes with high quantities of water, to minimize energy demand from purchased fuel.

Resource Recovery Potential[7]

There is little resource recovery potential with respect to cement kilns and calcinors as the existing industrial facilities already sell their end product and recover heat from the process for combustion air preheating or other uses. The primary potential for these facilities is that they provide existing facilities for the incineration of specific wastes.

Environmental Factors[7]

As a dedicated waste disposal facility, cement kilns give a product that is suitable for sale or disposal to landfill. A large volume reduction is achieved and the resulting calcined products typically show low leachability. Additional air emissions are invariably produced during the process, and adequate treatment systems must be employed.

LIQUID INJECTION

Process Description

Liquid injection represents a special application of a waste thermal processing technology (Figure 3.4.5). A key component of the liquid injection incinerator is the waste atomization device or nozzle. The purposes of injecting the liquid as a spray are to:[8]

- break-up the liquid waste into fine droplets, and
- introduce the liquid wastes into the incinerator at a specific location

Normally, liquid injector incinerators consist of two stages.[9] The primary chamber is usually a burner where combustible liquid and gaseous wastes are introduced. Noncumbustible liquid and gaseous wastes are usually introduced downstream of the burner into the secondary chamber. Single-stage incinerators are used for systems handling only combustible wastes.

The configuration of a liquid injection incinerator can be horizontal, vertical upfired, vertical downfired, or sloped. The selection of configuration usually depends on the characteristics of wastes.

In general, waste liquid cannot be oxidized effectively in conventional burners. A high heat release burner is usually necessary for complete combustion of these liquid wastes.[10] The burners must be located to prevent flame impingement on walls and, in the case of multiburner systems, interference with one another.

Waste Inputs

Liquid injection incinerators are versatile devices which can be used to dispose of many pumpable wastes, such as contaminated water and waste solvents. This technology may be considered for thermal processing of the following wastes (UCD classification): 211-217; 221-223; 231.

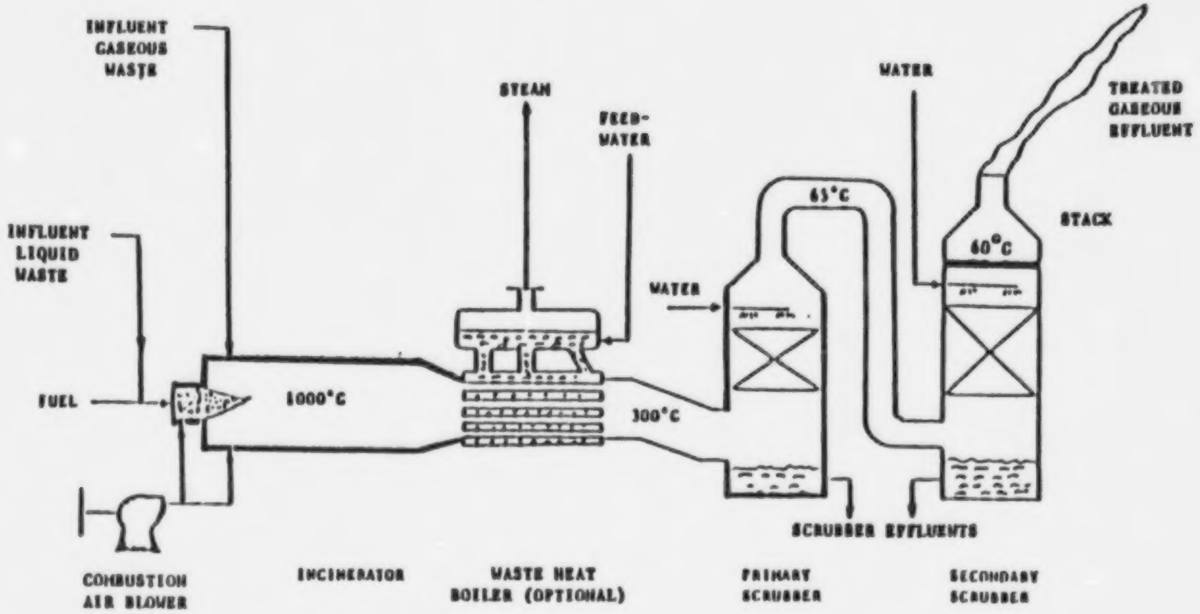
INFLUENT GASEOUS WASTE
INFLUENT LIQUID WASTE
FUEL
1000°C
STEAM
FEED-WATER
WATER
300°C
65°C
WATER
60°C
TREATED GASEOUS EFFLUENT
STACK
SCRUBBER EFFLUENTS
COMBUSTION AIR BLOWER
INCINERATOR
WASTE HEAT BOILER (OPTIONAL)
PRIMARY SCRUBBER
SECONDARY SCRUBBER

FIGURE 3.4.5 : LIQUID INJECTION INCINERATOR WITH HEAT RECOVERY

SOURCE: KIANG, 1976

Effluent and Residuals

The liquid injection incinerator system produces two or three effluent waste streams. Liquid and gaseous effluent streams are related to the air pollution control system incorporated to treat air emissions. Wet scrubbing systems may produce a relatively concentrated liquid effluent that requires treatment, or they may incorporate a recirculation and drying feature that eliminates the liquid stream (i.e., contaminants are then removed as dry particulate). The gaseous effluent stream after being treated by the air pollution control system is discharged by means of a stack. The solid inorganic residues comprise the third effluent stream which are made up primarily of slag particulates and other nonburnables and scrubber dry particulate which require ultimate disposal, generally to a land disposal facility.

Implementation, Reliability [11]

Liquid injection incinerators represent a widely used proven technology for pumpable waste treatment. Liquid injection is in daily use throughout the U.S.A. both at industrial locations and central treatment facilities. Liquid injection systems contain no moving parts and generally require the least maintenance of all types of incinerators. On-line destruction efficiencies of over 95% have been achieved.

Liquid injection incinerators are highly sensitive to waste composition and flow changes. Thus, storage and mixing tanks are necessary to ensure a reasonably steady and homogeneous waste flow.

Process Applications [6]

Liquid injection incinerators are generally applicable to the ultimate disposal of combustibles in pumpable liquid wastes. Due to their size, liquid injection systems are usually dedicated to specific plant applications.

This type of incinerator can also be used to dispose of solid wastes, either by melting or by dissolving them into a liquid material. When preheating a waste, it is essential to ensure that undesirable preliminary chemical reactions such as polymerization, nitration, etc., will not occur. Provisions should also be made to prevent the release of gases during preheating.

Wastes treated by liquid injection incinerators include PCBs, chlorinated hydrocarbons, brominated hydrocarbons, pesticide and insecticide plant waste, vinyl chloride, fluorinated herbicide wastes, and nitrochloride-benzene wastes.

Economic Factors

The size of liquid injection incinerators is usually in the range of 1 to 150 GJ/h. Smaller units are usually factory fabricated package units. Capital costs are dependent upon environmental requirements for the waste to be destroyed. Maintenance cost is usually low.

Operating costs are very dependent upon the calorific value of the waste and its water content, etc. Operation often requires only one or two trained personnel.

Energy Requirements

Energy requirements vary with the type of waste processed. No fuel is required for self-combustible wastes.

Resource Recovery Potential

Liquid injection incinerators have been designed to recover hydrochloric acid, hydrobromic acid, phosphoric acid, sodium carbonates and precious metal catalysts. The recovery of waste heat energy as steam is also possible for liquid injection incinerators.

Environmental Factors

Liquid waste of the type to be destroyed in a liquid injection incinerator normally has little resulting ash which is removed in the scrubber system either in the dry state or as solids in the liquid stream from a wet scrubber.

Liquid injection incinerators are a well-proven technology with many operating plants throughout the world for treatment of liquid combustible waste. The environmental factors relate specifically to the resulting ash of the incinerated waste, liquid discharge from wet scrubber systems, if employed, particulate removed from the flue gas stream and flue gas emissions to the atmosphere.

Latest technology for flue gas scrubbing results in minimum liquid waste to be treated (or no liquid waste at all), leaving only particulate to be disposed of. The air emissions are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many liquid injection incinerators as latest state-of-the-art incineration technology when coupled with appropriate air pollution control systems.

FLUIDIZED BED

Process Description[12]

A fluidized bed incinerator (Figure 3.4.6) consists of a vertical refractory lined vessel containing a bed of granular material resting upon a distributor plate. Combustion air is introduced at the bottom of the incinerator and rises vertically through the distributor plate into the granular bed. Silica sand is normally used as the bed material, but limestone or other materials have also been used. If the waste contains inorganic materials, the bed can, depending upon bed material, be replaced gradually with the inorganic material generated through incineration. Continuous bed material removal and make up is practiced for this situation.

The upward flow of air through the bed causes fluidization of the bed material and rapid mixing of the waste material, air and bed material. The waste is normally fed directly into the bed or above the bed. Combustion takes place within the bed with some combustion being completed in the freeboard area above the bed (a function of the waste characteristics, bed material and design of the unit). The temperature within the bed typically ranges from 600° to 900°C.

Waste Inputs

Fluidized bed incinerators can be used to dispose of solid, liquid, sludge, slurry, and gaseous wastes. Solid materials may require processing for size reduction to facilitate feed to the fluidized bed. This technology may be considered for thermal processing of the following wastes (UCD Classification): 211-217; 221-228; 241, 254, 262, 281; 289; 455.

Effluent and Residuals

Ash and ground fines of bed material are carried out of the fluid bed incinerator with the combustion product gas stream to the scrubbing systems which may include electrostatic precipitators for particulate removal, wet or wet/dry scrubbers for particulate and other chemical pollutant scrubbing. Scrubber waste water from wet scrubber systems may require further treatment before being discharged from the facility.

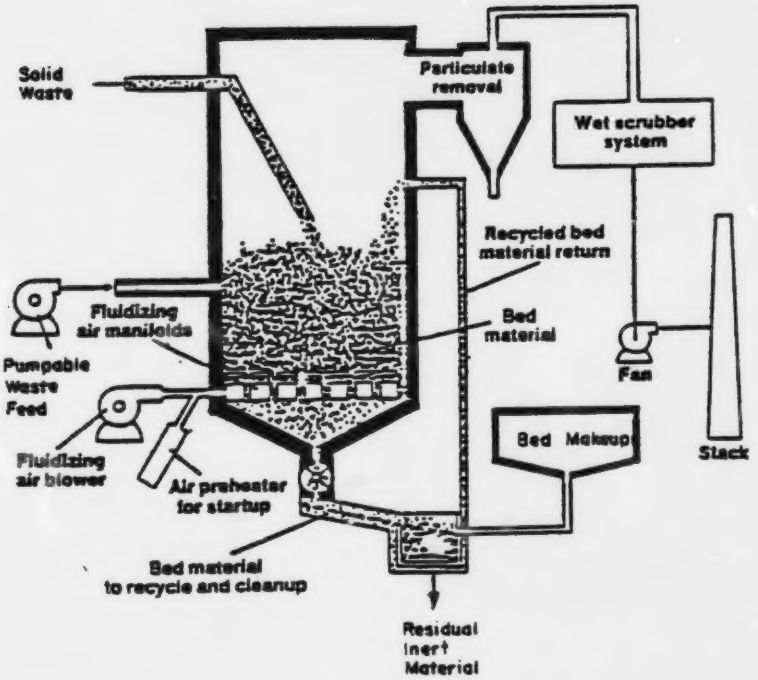
Solid Waste
Particulate removal
Wet scrubber system
Recycled bed material return
Fluidizing air manifolds
Bed material
Pumpable Waste Feed
Fan
Fluidizing air blower
Air preheater for startup
Bed Makeup
Stack
Bed material to recycle and cleanup
Residual Inert Material

FIGURE 3.4.6 : FLUIDIZED BED INCINERATION SYSTEM

The physical and chemical nature of the resulting ash and fines will be a function of the waste material chemical properties and the material used in the bed. Chemical reactions occurring during the combustion process in the bed may form other chemical compounds depending upon the waste and bed material. This permits matching of specific waste streams to bed material to achieve a combination of combustion and calcining that may produce an inert ash or reusable product the same as described under Calcination/Cement Kiln.

Implementation, Reliability

Fluidized bed incinerators have been used successfully for refinery, paper mill and sewage treatment plant sludge incineration. They have also been used as ore roasters, calciners, etc. There has been some attempt at aqueous organic waste incineration.

Although fluidized beds have been used for many years in various industries, their use in hazardous waste incineration is still essentially at a demonstration level. It is generally agreed, however, that this approach to waste incineration offers significant potential for the future for certain classes of wastes.

Process Applications

The fluidized bed incinerator may be considered for the incineration of liquids, sludges, and wastes containing a high ash content.[13]

Fluidized beds are primarily used to dispose of sludges from municipal wastewater treatment plants, petroleum refineries, and pulp and paper mills. There is limited data related to their use as waste incinerators. Wastes which have reportedly been burned in fluidized beds, however, include organic wastes from pharmaceutical manufacturers, phenolic wastes, and methyl methacrylate.[6]

Economic Factors

Capital costs for a waste fluidized bed incinerator facilty are highly dependent upon the waste quantity, type of waste, and the necessary pollution control system to meet environmental needs that are to be handled at the facility.

Maintenance costs are high for these facilities on a dollar basis, but on a per unit weight of waste treated are relatively low provided a reasonably high level of utilization of the equipment is maintained.

Energy costs are highly dependent on the calorific value of the waste, percent water in the waste, and available waste to offset purchased fuel that might be required for some waste treated. These costs are very dependent upon the managerial control of scheduling various wastes to minimize purchased energy requirements while insuring that the mix of chemicals will not result in final combustion products that may destroy slag properties, ash properties, or cause deposits in waste heat boilers or scrubbing systems affecting their performance.

Energy Requirements

Energy requirements are highly dependent on the calorific value of the waste to be destroyed and the availability of waste fuels. Proper management of scheduling will reduce energy requirements to a minimum.

Resource Recovery Potential

In some instances, the fluidized bed incinerator can be designed to recover specific compounds from the bed when the bed material used is capable of chemically reacting with the waste material to be destroyed at the temperatures involved. This end product from the bed, depending upon the waste and bed materials, may be directly landfilled or reused or further treated depending upon its chemical and physical properties.

As in any thermal process with high temperature flue gas, waste heat can be recovered in the form of steam of hot water or used to preheat combustion air.

Environmental Factors

Fluidized bed incinerators are a well-proven technology with many operating plants throughout the world. Environmental factors relate specifically to the resulting ash of the incinerated waste, liquid discharge from wet scrubber systems, if employed, particulate removed from the flue gas stream, and flue gas emissions to the atmosphere.

Ash disposal is to secure landfill sites for ash that is not suitable for reuse; to municipal solid waste landfill sites for inert ash; to metal recovery or reuse in other forms where warranted.

Latest technology for flue gas scrubbing results in minimum liquid waste to be treated (or no liquid waste at all) leaving particulate to be disposed of in the same manner as the ash. Air emissions are minimized through the use of proper air pollution control systems, sized and matched to the type and quantity of waste to be handled by the facility.

Regulatory agencies have accepted many fluidized bed incinerators as latest state-of-the-art incineration technology when coupled with appropriate air pollution control systems.

AT SEA INCINERATION

Process Description [14,15]

At sea incineration (Figure 3.4.7) is not a unit thermal processing technology, but an application of existing technology to waste incineration, usually a liquid injection unit mounted on a ship. Wastes are burned in the incinerator at locations in the open sea away from populated areas and shipping lanes.

A typical ship-mounted incinerator is exemplified by the M/T Volcanus. Two vertical upfired incinerators are located at the stern of the ship. Each incinerator is equipped with three burners located roughly symmetrically around the bottom of the furnace. These burners have a rotating cup fuel injection system that provides vortex turbulence and distribution of feed throughout the entire chamber. No air pollution control equipment is used in the system; the incinerators exhaust directly to the atmosphere.

Waste Inputs

The principal categories of wastes which are considered for disposal at sea include organic and organic/inorganic liquids, slurries, and sludges. Some solid wastes may be disposed of by the "at sea incineration" approach, if they are soluble in liquid wastes, fuel oil or water, or if they can be emulsified in waste. Wastes that can be considered for thermal processing include (UCD Classification): 213; 216; 222; 225-228; 241-242.

Effluent and Residuals

At sea incineration produces an air emissions effluent and potentially a solid ash residue. The basic principle of at sea incineration is that any effluent and residue would be dispersed and diluted in the air and water to undetectable concentrations.

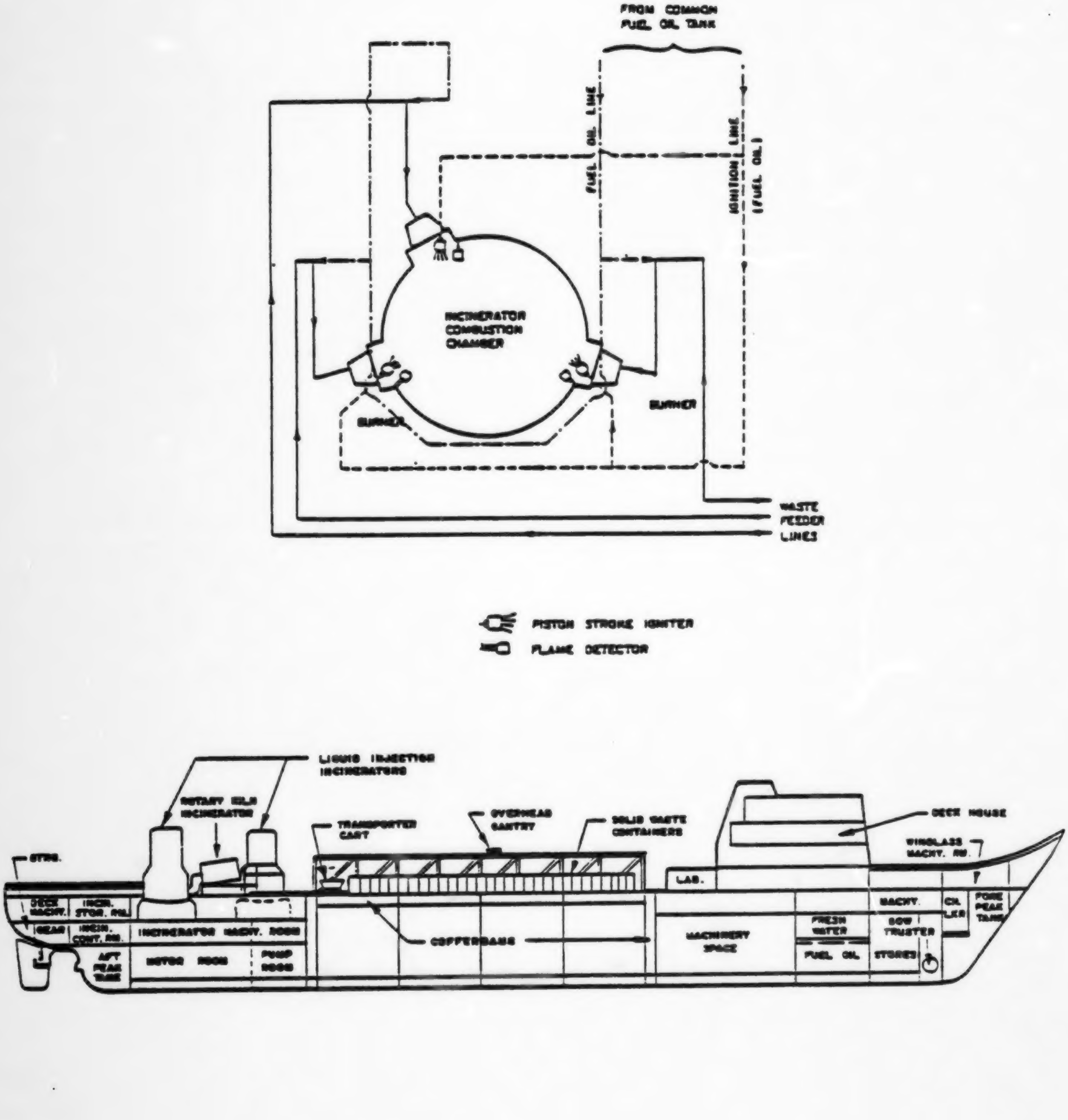
FROM COMMON FUEL OIL TANK
FUEL OIL LINE
IGNITION LINE (FUEL OIL)
INCINERATOR COMBUSTION CHAMBER
BURNER
BURNER
WASTE FEEDER LINES
PISTON STROKE IGNITER
FLAME DETECTOR
LIQUID INJECTION INCINERATORS
ROTARY KILN INCINERATOR
TRANSPORTER CART
OVERHEAD GANTRY
SOLID WASTE CONTAINERS
DECK HOUSE
WINDLASS MACHY. RM.
STRG.
DECK MACHY.
INCIN. STOR. RM.
GEAR
INCIN. CONT. RM.
INCINERATOR MACHY. ROOM
AFT PEAK TANK
MOTOR ROOM
PUMP ROOM
COFFERDAMS
LAB.
MACHINERY SPACE
FRESH WATER
FUEL OIL
MACHY.
BOW TRUSTER
STORES
OIL LKR
FORE PEAK TANK

FIGURE 3.4.7 : AT SEA INCINERATION

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1977

Implementation, Reliability

Incinerator ships have been used in European waters since 1969 and, on occasion, also in the Gulf of Mexico, for destruction of organochlorine wastes. At one time there were four such vessels; currently, only two are in operation: the M/T Vulcanus and the K/B Vesta.

An incinerator ship service requires a land-based support network typically consisting of waterfront storage tanks, waste processing and handling equipment, a laboratory for waste analysis, a cargo transfer terminal, and an inland transportation system to haul wastes.

Process Applications[15]

At sea incineration is a relatively new disposal technique and little is known about its long-term effects. The first U.S. experiments were conducted during 1974 and 1975 in the Gulf of Mexico on waste generated from the production of glycerine, vinyl chloride, epichlorohydrin and epoxy resins. In this test, wastes were incinerated at a temperature of 1300°C. Destruction efficiencies of toxic organics were reported to be in excess of 99.9%. Another test was performed on Agent Orange in the Pacific Ocean during 1977 and 1978. This test showed a destruction efficiency of 99.99% at 1250°C and a residence time of about 1 second.

At the present time, only liquid, liquifiable, and dissolvable organic waste can be handled by at sea incineration.

Economic Factors

At sea incineration is relatively capital intensive and expensive to operate. Capital cost for an at sea incinerator includes three major components: incinerator plant, ship, and on-shore facility. Costs per unit of material destroyed will be highly dependent upon the actual utilization of the ship/incinerator plant which, due to the long turn-around time from port to the sea incineration area, may be several times the cost of a land-based facility.

Should environmental constraints be placed upon pollutants emitted from at sea incinerator ships, the capital costs will be further increased along with other operating costs.

Energy Requirements

With careful planning, no auxiliary fuel should be required for at sea waste incineration if highly combustible wastes are being burned. However, auxiliary fuel for start-up and shut-down is required.

Resource Recovery Potential

At sea incineration is not designed for resource recovery. However, it may be possible to recover metals from incineration ash, depending upon the type of wastes being burned.

Environmental Factors

At sea incineration presents an alternative to land based incineration. However, there are potential risks of negative environmental impacts to air quality, water quality and land use. Some local impacts on air quality result from at sea incineration and within 10-15 km of the incinerator ship, but beyond about 15 km the effects of dispersion and neutralization should significantly reduce air impacts.

The ability of seawater to assimilate hydrogen chloride without measurable change is well known. The most serious environmental threat to water quality posed by incineration at sea lies in the accidental spillage of wastes during loading or waste handling on-shore. Control of potential spills must be a major component in the design and operation of the land-based support facilities. At sea incineration should not be considered in fresh water areas, such as The Great Lakes, because of the limited dispersion available and the use of these waters as the primary source of fresh water to all the adjoining land mass.

MOLTEN SALT INCINERATION

Process Description [16,17]

Molten salt incineration (Figure 3.4.8) is a developing technology for thermal processing of wastes containing organics and other combustibles. Waste materials and combustion air are introduced beneath the surface of a molten salt bath. The molten salt bath is composed of 90% sodium and 10% sodium sulfates. Hydrocarbons and air react inside the bed forming carbon dioxide and water vapour. Hot gases rise through the molten salt bath, pass through a secondary reaction zone, and then through the off-gas clean-up system before discharging into the atmosphere. The incineration temperature of a sodium sulfate and sodium carbonate salt bath can be in the range of 750 - 1000°C. Sodium carbonate is used to remove acidic gases, such as hydrogen chloride and sulphur dioxide. Sodium sulfate serves as the catalyst for the combustion of carbon. At normal incineration temperatures, halogens react to form sodium halides. Phosphorus, sulphur, arsenic, and silicon form their respective oxygenated sodium salts, while iron forms iron oxides. Because of the relatively low temperature, nitrogen oxide formation is low. Other salt mixtures, such as sodium hydroxide/potassium hydroxide and sodium carbonate/lithium carbonate/potassium carbonate, also have been tested. The salt can be withdrawn batchwise or continuously and regenerated or handled for ultimate disposal. Most of the ash and acidic products of combustion are retained in the molten bed rather than emitted to the atmosphere. However, some air pollution control equipment will likely be required.

Waste Inputs

Molten salt incinerators are being developed to process organics and many inorganic wastes, including low level radioactive wastes. They are being designed to incorporate solid, liquid, sludge, and gaseous wastes. Appropriate for treatment of the following wastes (by UCD classification): 241-245; 444; 513; 529.

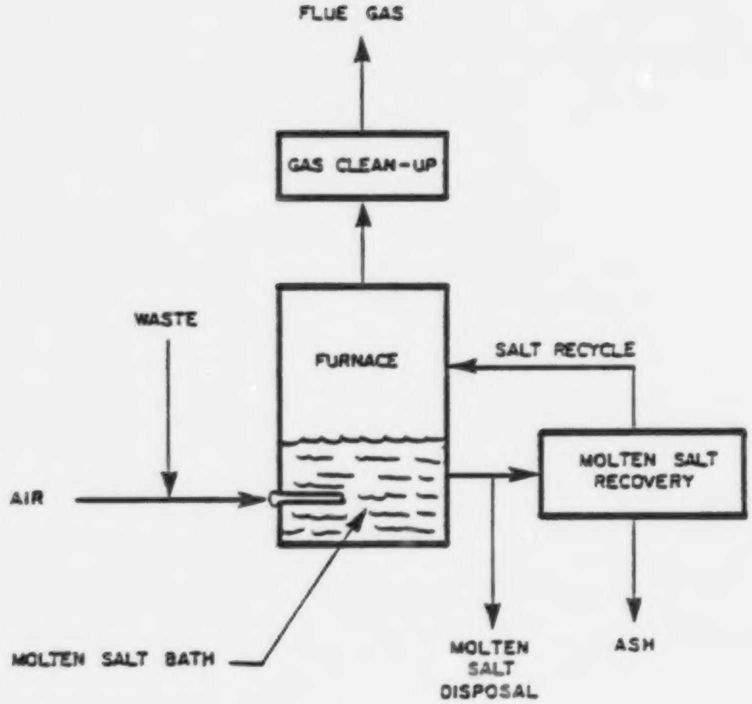
FLUE GAS
GAS CLEAN-UP
WASTE
FURNACE
SALT RECYCLE
AIR
MOLTEN SALT RECOVERY
MOLTEN SALT BATH
MOLTEN SALT DISPOSAL
ASH

FIGURE 3.4.8 : MOLTEN SALT INCINERATION SYSTEM

SOURCE: KIANG, 1976

Effluent and Residuals

Molten salt systems produce air emissions as well as two residual streams for disposal. The residual streams basically include waste molten salt that is not recovered, and recycled and process ash residues. The waste salt and process ash will require ultimate disposal.

Implementation, Reliability

Molten salt incinerators are still in the developing stage. No full size units are in operation. A pilot-scale molten salt unit capable of combusting up to 90 kg per hour of wastes has been operated in the United States to burn a variety of wastes. This unit, with its rather small capacity, is the only example of molten salt combustion of waste. Before this technology can be endorsed as an alternative technology for waste treatment in the Province of Ontario, more demonstrations must be carried out at conditions more nearly reflecting commercial-scale operations. Of the developing technologies, however, molten salt incineration may prove effective in near future applications to waste management.

Process Applications

Molten salt incineration appears to be applicable to numerous waste types including pesticides, combustible industrial wastes, and hazardous chemicals including various carcinogens and low-level radioactive wastes.

Pilot plant tests have been carried out with various wastes, such as PCB, chloroform, trichloroethane, diphenylamine HCl, nitroethane, aqueous slurry of tributylphosphate, para-arsenilic acid, DDT powder, malathion, chemical warfare agents (such as VX, GB, and mustard).

The advantages of molten salt systems include: compact size may make it possible to design a unit to be portable; at lower combustion temperatures than in conventional units; retention of some products of combustion in the melt which reduces the loading on air pollution control devices.

The limitations of the molten salt system include: ineffectiveness in treating wastes with a high ash content; low temperatures which may not be high enough to completely combust hard-to-burn wastes; potential problems with continuous regeneration of the molten salts in commercial-scale operations.

Economic Factors

No economic factors are available for these types of systems due to the experimental/developmental nature of this technology.

Energy Requirements

Dependent on the heating value of the waste.

Resource Recovery Potential

Depending on the waste characteristics, it may be possible to recover metals from the contaminated molten salt. It may also be possible to consider waste heat recovery from the hot flue gas.

Environmental Factors

The molten salt batch serves as a "scrubber" for gases and solid particulates. However, additional control equipment such as a scrubber system may be needed. The contaminated salt may be regenerated or handled for ultimate disposal. The residual ash and spent molten salt requires ultimate disposal in a secure landfill.

WET AIR OXIDATION

Process Description[18,19]

Wet air oxidation is a thermal process in which combustible material is oxidized by air or oxygen in the presence of liquid water (Figure 3.4.9). Low temperatures (150 -300°C) are required to achieve useful reaction rates. Elevated pressures are required to maintain a liquid phase. The process is operated continuously with respect to both liquid and air or oxygen addition. The waste is pumped via a high pressure pump through a heat exchanger and then into a reactor where compressed air or oxygen is added. The oxygen reacts with the organic matter in the waste slurry to produce mainly carbon dioxide and water. Due to the exothermic nature of the reaction, heat is produced which raises the temperature of the reactor contents. The effluent from the wet oxidation reactor is heat exchanged with the incoming waste.

Almost any combustible material which is in an aqueous medium can be oxidized by this process. The wet air oxidation process provides efficient means for the recovery of energy from relatively dilute waste streams. The reaction occurs and the energy is liberated in the liquid phase with no barrier to the transfer. The energy can, therefore, be recovered with the highest degree of efficiency.

Waste Inputs

Wet air oxidation is applicable to aqueous waste streams containing between 1% and 20% of oxidizable (generally organic) contaminants. It can treat most organic wastes including highly chlorinated compounds or those containing nitrogen or sulphur and refinery spent caustics. More concentrated wastes can be treated by wet air oxidization after dilution with water. This may be appropriate for specific wastes. Wet air oxidation is appropriate for processing of the following waste streams (UCD classification): 211-217; 221-225; 227; 251; 282-289.

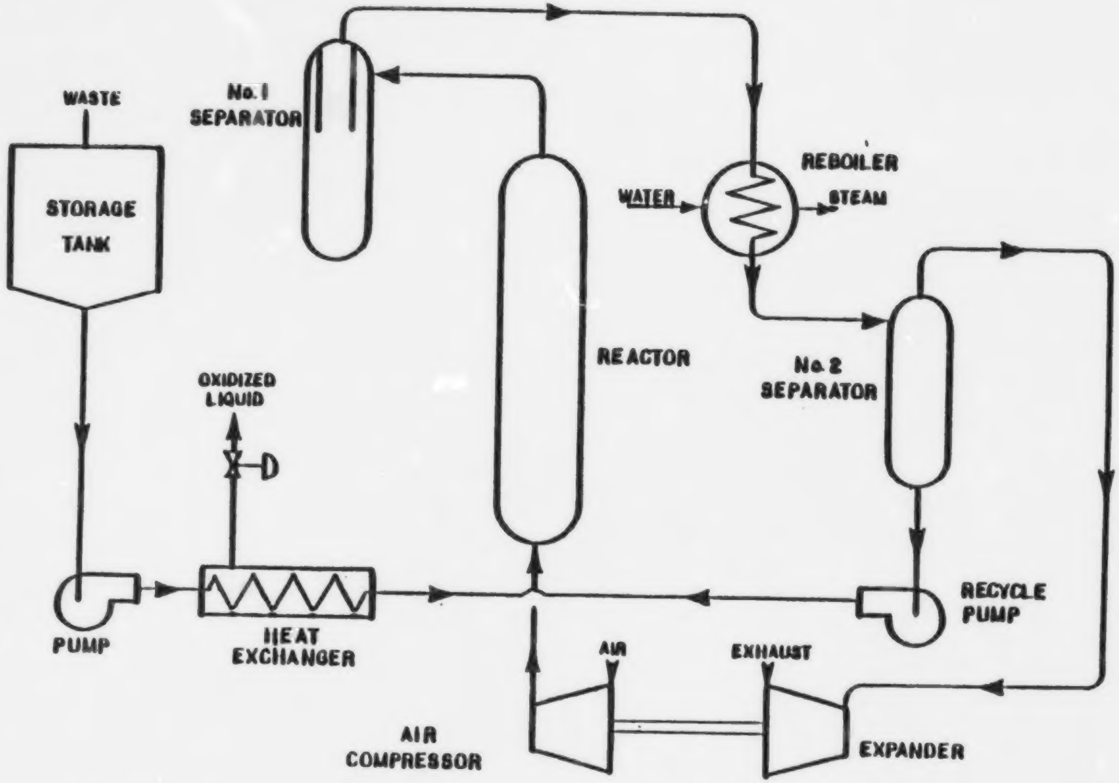
WASTE
STORAGE TANK
No. 1 SEPARATOR
REACTOR
WATER
REBOILER
STEAM
No. 2 SEPARATOR
OXIDIZED LIQUID
PUMP
HEAT EXCHANGER
RECYCLE PUMP
AIR
EXHAUST
AIR COMPRESSOR
EXPANDER

FIGURE 3.4.9: WET AIR OXIDATION

SOURCE: PRADT, 1972

Effluent and Residuals

Wet air oxidation systems produce two effluent streams a gaseous discharge and a liquid effluent stream, each requiring further treatment. The gaseous effluent contains nitrogen, carbon dioxide, some residual excess oxygen, steam and some other gaseous combustion products. The liquid effluent stream contains nonoxidizable materials, oxidized inorganics mostly in a highly oxidized state, and partially oxidized residual organics. Polishing steps such as precipitation and filtration must be employed to remove inorganics from the liquid effluent prior to discharge. Residual organics can be further biodegraded utilizing biological treatment processes.

Implementation, Reliability

Wet air oxidization has been proven technically on sewage sludge and pulp mill effluents. It is also suitable for treating a broad range of industrial wastewaters. The process chemistry has proved to be reliable. Mechanical and corrosion problems associated with the process in its early stages of development have been reduced.

Process Applications

Wet air oxidation has been used for many years to partially oxidize sewage sludge and pulp mill effluent to render it more dewaterable. Units are in the process of being installed in Ontario for thiocyanate wastes in the steel industry and for a waste stream from a diversified chemical producer.

Research and development has shown that wet air oxidation is potentially applicable in a wide range of industrial waste waters containing moderate concentrations of organic contaminants, e.g., wastes from food and beverage industry, pharmaceutical industry, pulp and paper, organic chemicals manufacturing, refineries, automotive painting, etc. The attractive feature of wet air oxidation is its ability to treat relatively dilute wastes without a preconcentration step.

Economic Factors

Capital and operating costs are highly dependent on the specific application and scale of operation. The process is capital intensive, capital charges being generally the highest element of annual costs for the process. Maintenance costs have proven to be very high (approaching 10% of initial capital cost annually in some cases). Operating costs are variable depending on the waste characteristics, source of energy, etc.

Energy Requirements

The process may be a net producer of thermal energy if the concentration of organic contaminant is sufficiently high and the pressure and temperature requirements for the waste stream are low.

Resource Recovery Potential

The recovery of resources is practical in some process applications. Paper mill wastes containing fibre and filler clay can be wet oxidized, destroying the fibre while allowing the filler clay to be settled and recovered from the liquid phase effluent. Ammonium sulfate can be recovered from wet air oxidation of ammonium thiocyanate.

Environmental Factors

The products of oxidation are released in an aqueous environment where they are scrubbed in passing through the liquid. This is particularly important for wastes containing chlorine, nitrogen, and sulphur. Chlorine remains for the most part in solution as hydrochloric acid, or as a chloride salt. Sulphur is oxidized to sulfate and mostly remains in solution as an acid or salt. Nitrogen hydrolyzes to ammonia and it generally remains in solution.

Residual organics also remain in solution; these are generally partially oxidized species such as low molecular weight carboxylic acids or alcohols. These species are quite refractory to further oxidation, but can be discharged to a sewage treatment facility where they may be further reduced in its biological process.

PLASMA ARC/MICROWAVE PLASMA DISCHARGE

Process Description [20,21]

Plasma arc/microwave plasma discharge reactors (Figure 3.4.10) are thermal processing technologies that are in the development stage. They are designed to destroy waste streams by pyrolyzing waste materials using intense energy levels. The plasma reactor is a device that utilizes electrical or microwave technologies to change minute quantities of almost any gas into the hottest sustainable flame - up to 50,000°C. There are two types of plasma reactors: plasma arc-torch and microwave plasma discharge.

Plasma arc pyrolysis is possible because the "plasma flame" can be generated in the total absence of oxygen. It is the oxygen (air) required to sustain combustion in conventional incinerator plants that makes true pyrolysis in incinerators unattainable.

The plasma arc flame is generated by the following steps:

- Gas (argon, helium, hydrogen, oxygen, etc.) is introduced in small quantities to create a swirling motion that keeps the plasma flame in the centre of the torch, away from metal parts and side walls of the reaction chamber.

- An electrical discharge is established (plasma arc flame) and maintained between the electrode inside the torch and any external elecrical conductor.

- The plasma flame then converts electrical energy into heat energy in an extremely efficient manner.

In the plasma arc reactor, the ultra high arc temperature of 50,000°C is sustained to provide the endothermic heat requirements of pyrolysis. Intense ultraviolet radiation enhances volatilization and thermal cracking of organic matter.

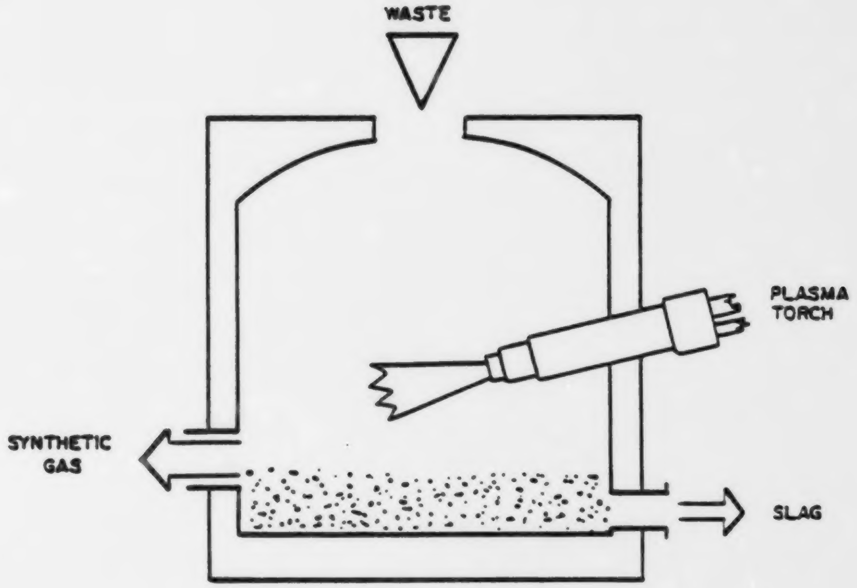
WASTE
PLASMA TORCH
SYNTHETIC GAS
SLAG

FIGURE 3.4.10 :PLASMA ARC REACTOR

SOURCE: KIANG, 1976

In the pyrolytic zone, the high temperatures cause reduction of all species to atomic entities prior to recombination into low-molecular-weight gases. Plasma arc technology is applicable to most organic waste, in both solid and liquid form. Concurrently, the system could return energy up to several times the electrical energy input. Recoverable energy would be in the form of sensible heat from the combustible byproducts. The inorganic fraction of the waste is recovered as slag.

The basic elements of a microwave plasma discharge reactor are:

1. a microwave generator or source of power;
2. a waveguide which leads the microwave power from the generator to a resonant cavity, which surrounds the reactor;
3. a reaction chamber, which must be made of silica or quartz to minimize dielectric losses;
4. a system for generating or feeding vapors, or reactants or condensed phases into the reaction chamber;
5. a system for controlling pressure and flow; and
6. a system for collecting reaction products.

Waste Inputs

Plasmas are initiated within gas mixtures, either inert gases (e.g., Ar, He), reactive gases (e.g., N_2, Cl_2, O_2, H_2, CO), inorganic vapors, organic vapors, or other gas mixtures. Solids and liquids exposed to the high energy plasma reaction will undergo destruction of their molecular makeup. Suitable waste materials for plasma reactions are not specifically defined, since the technology is still in the development stage.

Effluent and Residuals

The product gases from plasma reactors are combustible gases with some heating value and may be useful as an auxiliary fuel. The gaseous effluent stream requires wet scrubber treatment to remove halogens and other off-gases prior to discharge. A liquid effluent from the scrubber may require pretreatment (e.g., pH adjustment) prior to discharge to a wastewater treatment plant. The residual slags from plasma arc reactors are predominantly inorganic and require ultimate disposal to landfill.

Implementation, Reliability

Plasma arc reactors have been demonstrated in the laboratory and offer promise as a future incineration option in waste management. It is now in the developmental stages. Plasma technology has been applied to the destruction of municipal and industrial wastes in at least one location in the United States. Because wastes can be variable in both chemical and physical characteristics, considerable research will be required to assure the reliability of microwave discharge techniques for complete combustion. In one of the first studies of the use of microwaves to treat hazardous wastes, microwave discharge was applied to nerve gas compounds and percent conversions range from 62 - 99.5%. The outlook for this technique is encouraging, particularly for highly toxic materials that cannot be handled in any other way. It is too early to predict the possible range of applications or the specific waste streams which could be treated cost effectively.

Process Applications

U.S. EPA funded projects are currently investigating the microwave plasma decomposition of waste. Experimental systems are designed to handle organic and metal-organic liquids and vapours. They could possibly be extended to handle fine powders or particulates. The small capacity of even a large microwave facility certainly precludes general use of the process for a large commercial size facility. There may be specialized applications for small quantities of oxidizable wastes which are not amenable to high temperature incineration.

Economic Factors

Since the plasma reactor is a relatively new technology, realistic cost estimates have not been developed yet.

Energy Requirements

Plasma arc systems could have large energy requirements. As development of the technology progresses, energy requirements will be more clearly defined.

Resource Recovery Potential

Plasma reactors may generate fuel gases from selected wastes which have a high heating value. The slag in the reactor could obtain recoverable metals depending on the type of wastes being processed.

Environmental Factors

Oxygen plasma treatment of waste materials containing halogenated compounds can give rise to gaseous emissions that include Cl_2O, $COCl_2$, HCl, Br_2, BrO_2, and Br_2O. Waste materials containing nitrogen compounds are likely to give rise to nitrogen oxides.

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3.5 SOLIDIFICATION/STABILIZATION AND ENCAPSULATION TECHNOLOGY

INTRODUCTION [1]

Solidification, stabilization and encapsulation technology may play an important role in the regional management of hazardous waste in the province of Ontario. It is appropriate to start this section by defining the terms 'solidification', 'stabilization', and 'encapsulation'. Current terminology in the field includes new terms and terms borrowed from other fields which are given new and specific meanings. As a matter of necessity, the following terms are used in this document with the meanings as noted below:

'Solidification' and 'Stabilization' as used here both refer to treatment systems which are designed to accomplish one or more of the following:

- Improve handling and physical characteristics of the wastes.
- Decrease the surface area across which transfer or loss of contained pollutants can occur.
- Limit the solubility of, or to detoxify, any hazardous constituents contained in the wastes.

Solidification implies that these results are obtained primarily, but not necessarily exclusively, via the production of a monolithic block of treated waste with high structural integrity. Stabilization usually involves addition of materials that ensure the hazardous constituents are maintained in their non-soluble and/or non-toxic form.

The term 'fixation' has fallen in and out of favour but is widely used in the waste treatment field as generally meaning any treatment system which solidifies and/or stabilizers the waste as described above. This is the restricted use of the term as it is employed in this document.

'Encapsulation' as used here is a technique of waste treatment involving isolation of the waste material by placing a jacket or membrane of impermeable, chemically inert material between the waste and the environment. Ideally, the jacket is bonded to the external surface of the solidified waste. Encapsulation of small particles is sometimes called 'microencapsulation', but this term is used by processors to describe a wide array of different techniques and therefore has no specific meaning.

STABILIZATION/SOLIDIFICATION AND ENCAPSULATION TECHNOLOGY [1]

Several stabilization/solidification and encapsulation methods that are now available or under development have as their goal the safe ultimate disposal of wastes either via a productive way or by landfilling. The following major categories of industrial waste fixation systems are discussed in this section:

- Cement-based processes
- Pozzolanic processes (not including cement)
- Thermoplastic techniques (including bitumen, paraffin, polyethylene incorporation)
- Organic polymer techniques (including urea-formaldehyde, unsaturated polyester and surface encapsulation techniques)
- Glassification and production of synthetic minerals or ceramics.

APPLICABILITY OF TECHNOLOGY [2]

Not all wastes justify treatment. The practical and economic decision concerning which wastes should or should not be submitted to expensive treatment systems is based upon an overall consideration of the amount, composition, physical properties, location, and disposal problems associated with the specific waste. Also of importance are the proven effectiveness and the costs associated with the commercially available treatment systems which are applicable to the specific wastes in question.

Wastes which may be designated as hazardous and are produced in large amounts are those most commonly considered for solidification/stabilization and encapsulation. Thus, the treatment of high volume hazardous waste forms the bulk of the discussion in this section.

Some types of non-hazardous wastes also benefit from treatment processes which would render the waste more easily manageable or less likely to lose undesirable constituents to the local groundwater. For instance, flue gas cleaning sludges have been the subject of a number of solidification/stabilization and encapsulation studies since their run-off water and leachates may typically represent a significant threat to the local groundwater.

Organic wastes are less amenable to currently available treatment technology than are inorganic wastes. This generalization holds for a wide variety of organic compounds with a diverse array of properties which occur in common waste streams. Wastes with greater than 10 to 20 percent organic constitutents are not generally recommended for treatment by current, commercial stabilization techniques as the organics interfere with the physical and chemical processes which are important in binding the waste materials together.

The ideal fixation process renders the noxious constituents chemically nonreactive and/or immobile so that no secondary containment is necessary for safe disposal. For example, incorporation into a stable crystal lattice effectively isolates noxious materials from environmental interactions, and maintaining the pH in the range of 9 to 11 immobilizes most multivalent cations (positively charged ions) as insoluble hydroxides and other compounds. Sludges with high concentrations of particular cations can be treated with additives chosen specifically to immobilize these contaminants. Anions (negatively charged ions), although typically much less toxic, are much more difficult to bind into an unleachable product. Chlorides and sulfates, the most common anionic sludge components, produce only a few insoluble salts. To contain anions such as these, the waste must be physically isolated from any leaching medium by secondary containment, sealing, or special landfill covers.

In addition to waste incompatibility problems, it is also necessary to note incompatibility of waste and stabilization/solidification materials over both long and short time periods. Though many reactions between waste materials and treatment reagents occur very slowly, the results may be accelerated deterioration of the treated waste and loss of containment properties. Table 3.5.1 summarizes major incompatibility problems that can be encountered with various waste solidification/stabilization techniques.

Some solidifying reagents may never set or harden if the wastes contain inhibiting materials. Silicate and cement reactions can be slowed by organics or high concentrations or by certain metals. Organic polymers can be broken down by solvents, strong oxidizers, or strong acids. Organic polymers are also degraded by ultraviolet radiation (exposure to sunlight).

To re-emphasize an important aspect of stabilization techniques, the waste most effectively stabilized/solidified and encapsulized consists mainly of inorganic materials in aqueous solution or suspension which contain appreciable amounts of toxic heavy metals and/or inorganic salts. It is also towards these waste types that most stabilization/solidification and encapsulation techniques are directed.

TESTING THE PHYSICAL AND CHEMICAL PROPERTIES OF STABILIZED WASTES[1]

The physical properties of the waste are modified by stabilization/solidification and encapsulation processes. The end product of many treatment processes is a solid block resembling low-strength concrete, which can be subjected to standard tests of physical properties so that its durability under field conditions can be predicted. Some processes produce a friable or soil-like product that must be subjected to tests more typically used for soil-cement. Prediction of chemical containment characteristics of these stabilized wastes from physical properties is much more difficult than prediction of long-term physical characteristics.

Physical testing of treated and untreated wastes is performed to determine partical size distribution, porosity, permeability and wet and dry densities. They are used to evaluate bulk properties, predict the reaction of a material to applied stress in embankments, landfills, etc., and evaluate durability. A variety of physical property tests are shown in Table 3.5.2.

TABLE 3.5.1 COMPATIBILITY OF SELECTED WASTE CATEGORIES WITH DIFFERENT WASTE SOLIDIFICATION/STABILIZATION AND ENCAPSULATION TECHNIQUES

Waste Component	Cement Based	Lime Based	Thermoplastic-Solidification	Organic Polymer (UF)*	Surface Encapsulation	Self Cementing Techniques	Glassification and Synthetic Mineral Formation
Organics:							
1. Organic solvents and oils	Many impede setting, may escape as vapour	Many impede setting, may escape as vapour	Organics may vapourize on heating	May retard set of polymers	Must first be absorbed on solid matrix	Fire danger on heating	Wastes decompose at high temperatures
2. Solid organics (e.g. plastics, resins, tars)	Good -- often increases durability	Good -- often increases durability	Possible use as binding agent	May retard set of polymers	Compatible - many encapsulation materials are plastic	Fire danger on heating	Wastes decompose at high temperatures
Inorganics:							
1. Acid wastes	Cement will neutralize acids	Compatible	Can be neutralized before incorporation	Compatible	Can be neutralized before incorporation	May be neutralized to form sulfate salts	Can be neutralized and incorporated
2. Oxidizers	Compatible	Compatible	May cause matrix breakdown, fire	May cause matrix breakdown	May cause deterioration of encapsulating materials	Compatible if sulfates are present	High temperatures may cause undesirable reactions
3. Sulfates	May retard setting and cause spalling unless special cement is used	Compatible	May dehydrate and rehydrate causing splitting	Compatible	Compatible	Compatible	Compatible in many cases
4. Halides	Easily leached from cement, may retard setting	May retard set, most are easily leached	May dehydrate	Compatible	Compatible	Compatible if sulfates are also present	Compatible in many cases
5. Heavy metals	Compatible	Compatible	Compatible	Acid pH solubilizes metal hydroxides	Compatible	Compatible if sulfates are also present	Compatible in many cases
6. Radioactive	Compatible materials	Compatible	Compatible	Compatible	Compatible	Compatible if sulfates are present	Compatible

* Urea-Formaldehyde Resin

TABLE 3.5.2 STANDARD TESTS OF PHYSICAL PROPERTIES[1]

Property	Source/Test Description
Bulk and dry unit weight	Appendix II of EM 1110-2-1906
Unconfined compressive strength	Appendix XI of EM 1110-2-1906 and ASTM Method D2166-66
Permeability	Appendix VII of EM 1110-2-1906
Wet/dry durability	ASTM Method D559-57
Freeze/thaw durability	ASTM Method D560-57

[1] Source: Guide to the Disposal of Chemically Stabilized and Solidified Waste (1980). EPA SW-872, US Army Engineer Waterways Exp. Station, Cincinnati, OH.

TABLE 3.5.3 PRESENT AND PROJECTED ECONOMIC CONSIDERATIONS FOR WASTE STABILIZATION/SOLIDIFICATION AND ENCAPSULATION SYSTEMS[1]

Type of Treatment System	Major Materials Required	Unit Cost of Material	Amount of Material Required to Treat 50 kg of Raw Waste	Cost of Material Required to Treat 50 kg of Raw Waste	Trends in Price	Equipment Costs	Energy Use
Cement-based	Portland Cement	$0.07/kg	50 kg	$ 3.50	Stable	Low	Low
Pozzolanic	Lime Fly Ash	$0.07/kg	50 kg	$ 3.50	Stable	Low Low	
Thermoplastic (bitumen-based)	Bitumen Drums	$.11/kg $27/drum	50 kg 0.88 drum	$20.50	Bitumen prices are rising rapidly because of oil prices	Very High	High
Organic Polymer (Polyester System)	Polyester	$.99/kg $2.44/kg $17/drum	20 kg of polyester-catalyst mix	$28.50	Price could rise rapidly due to oil shortage	Very High	High
Surface Encapsulation (Polyethylene)	Polyethylene	Varies	Varies	$ 5.00*	Price could rise rapidly due to oil shortage	Very High	High
Self-Cementing	Gypsum (from waste)	**	5 kg	**	Stable	Moderate	Moderate
Glassification/ Mineral Synthesis	Feldspar	$0.07/kg	Varies	--	Stable	High	Very High

* Based on the full cost of $100/tonne.

** Negligible but energy cost for calcining are appreciable.

[1] Source: Guide to the Disposal of Chemically Stabilized and Solidified Waste (1980). EPA SW-872, US Army Engineer Waterways Exp. Station, Cincinnati, OH.

Chemical leach testing of wastes is a technique that is used to examine or predict the chemical stability of treated wastes when they are in contact with aqueous solutions that might be encountered in a landfill. The procedures demonstrate the degree of immobilization of contaminants produced by the treatment process. A great number of techniques for leach testing are available. Unfortunately, no single leach testing system can duplicate the variable conditions that may be encountered by landfilled treated wastes. Furthermore, there is no uniform opinion as to how each of these variables should be treated in a testing procedure.

ECONOMICS [1]

Capital and operating costs of solidification, stabilization and encapsulation processes vary greatly depending on the type of technology and the type and characteristics of waste to be treated. Table 3.5.3 illustrates the present and projected economic costs for such technology. It should be noted, however, that such figures do not include the final disposal cost of treated waste (e.g. landfilling of stabilized waste).

CEMENT-BASED PROCESSES

Process Description (Figure 3.5.1)[1,3,4,5]

Cement-based processes are designed to incorporate common (Portland) cement as a stabilization agent to isolate hazardous wastes. Portland cement is produced by firing a charge of limestone and clay or other silicate mixtures at high temperatures. The resulting clinker is ground to a fine powder to produce a cement that consists of about 50% tricalcium and 25% dicalcium silicates, 10% tricalcium aluminate and 10% calcium aluminoferrite. The cementation process is brought about by the addition of water to the anhydrous cement powder. This first produces a colloidal calcium-silicate-hydrate gel of indefinite composition and structure. Hardening of the cement is a lengthy process brought about by the interlacing of thin, densely-packed, silicate fibrils growing from the individual cement particles. This fibrillar matrix incorporates the added aggregates and/or waste into a monolithic, rock-like mass.

The presence of certain inorganic compounds, however, can be deleterious to the setting and curing of the waste-containing concrete. Also, impurities such as organic materials, silt, clay, or lignite may delay the setting and curing of common Portland cement, as they may be present as dust or may coat the larger particles and weaken the bond between the particles and the cement. Soluble salts of manganese, tin, zinc, copper, and lead may cause large variations in setting time and significant reduction in physical strength. Salts of zinc, copper, and lead are the most detrimental. Other compounds that are especially active as setting retarders in Portland cement include sodium salts of arsenate, borate, phosphate, iodate, and sulfide.

A number of additives have been developed for use with cement to improve the physical characteristics and decrease the leaching losses from the resulting solidified sludge. Soluble silicate has reportedly been used to bind contaminants in cement solidification processes, but this additive causes an increase in volume to occur during the setting of the cement-waste mixture.

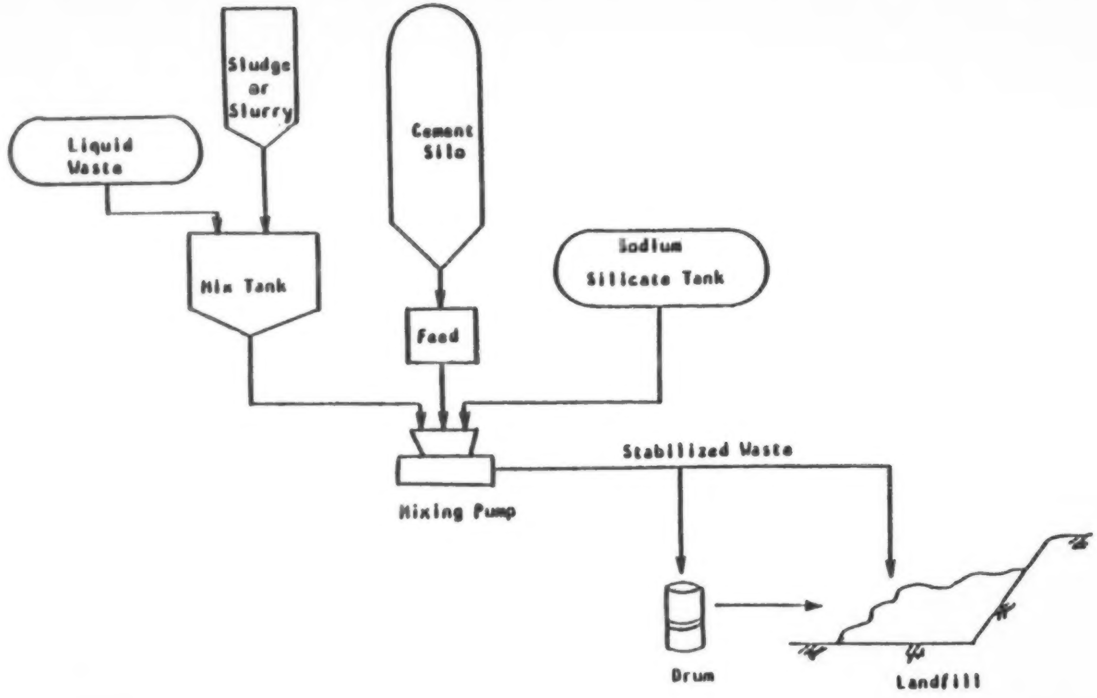

Sludge or Slurry
Liquid Waste
Cement Silo
Mix Tank
Sodium Silicate Tank
Feed
Stabilized Waste
Mixing Pump
Drum
Landfill

FIGURE 3.5.1 : CEMENT – BASED STABILIZATION PROCESS

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1980

Waste Inputs [1,4,5,6]

Many types of hazardous waste when slurried or suspended in water and mixed with cement will be incorporated into a rigid matrix that exhibits properties after curing, similar to low grade concrete. This process is especially effective for waste with high levels of toxic metals. At the pH of the cement mixture, most multivalent cations are converted into insoluble hydroxides or carbonates. Metal ions are also incorporated into the lattice structure of the cement matrix. Certain organic materials are compatible with the cement reactions. However, some organics and salts may inhibit the reactions and prevent setting of the treated waste. The waste accepted at a cement-based stabilization plant could be in the form of liquid, slurry, or sludge or dry solid mixed with other liquid wastes. Appropriate for stabilization of the following waste streams (by UCD classification): 111-113; 121-123; 131-133; 141-143; 151-152; 165; 248; 251; 282-286; 417; 431; 433; 441-443; 445; 447; 518.

Effluents and Residuals [5]

Cement stabilization results in an increased weight and volume of residues for disposal because of the additives utilized for processing. The stabilized waste can be containerized (e.g., in drums) and placed in a landfill or directly discharged into the landfill and allowed to set and achieve its ultimate strength within the cells.

Implementation, Reliability [5]

Cement-based stabilization processes are proven methods of waste isolation for predominantly inorganic contaminants. Impurities such as organic materials and some inorganics can be deleterious to the setting and curing of the waste containing concrete. In general, the technology and management of cement mixing and handling are well known, equipment is commonplace, and specialized labour is not required. The system is tolerant of most chemical variations. The natural alkalinity of the cement can neutralize acids, and cement is not affected by strong oxidizers such as nitrates and chlorates. Cement-based stabilization can be applied easily to a regional waste management program.

Process Applications[5]

This process has been commercially applied to wide range of wastes including radioactive, inorganic and organic residuals. Many stabilization processes are available under proprietary and commercial names. The largest number of applications so far has been in solidification and stabilization of radioactive waste and inorganic hazardous waste, including waste and pickle liquors, plating solutions, scrubber sludge, steel mill waste, air pollution control residues, heavy metal sludges and waste containing small amounts of organics.

Economic Considerations[5]

Both capital and operating costs are extremely variable depending on waste, type of process and additives used. Reported cost of processing cover a wide spectrum starting at a few dollars and up to hundreds of dollars per tonne of waste treated. However, cement stabilization of wastes may cost $30-$100/tonne. Cost of landfilling of stabilized waste should be added to such figures.

Energy Requirements[5]

Energy requirements for stabilization are primarily for electricity to run pumps, mixers and conveyors and does not represent a major fraction of operating cost. However, it should be noted that cement manufacturing is an energy intensive industry and cost of cement will escalate with the rising cost of energy.

Resource Recovery Potential[5]

Resource recovery potential is not very high for stabilized hazardous waste. However, stabilized low hazard waste (e.g., neutralized acids) may have potential value as building and construction materials.

Environmental Factors [5]

Cement stabilization techniques represent effective means of reducing hazards associated with waste and mobility of toxic substances as well as enhancing physical and structural properties of waste. This will result in reducing the potential for surface and subsurface pollution when disposing stabilized wastes in special landfills. However, care should be given to the proper disposal of treated waste to avoid contact with incompatible waste and potential leaching of entrapped contaminants.

Institutional Factors [5]

No unusual institutional constraints are expected during implementation of such technology. Furthermore, stabilization would be viewed favourably by regulatory and the public because of potential reduction of waste handling and disposal hazards. However, landfilling of stabilized hazardous waste may be subject to public opposition.

LIME-BASED (POZZOLANIC) PROCESSES

Process Description (Figure 3.5.2) [1,3,4,5,6]

Waste fixation techniques based on lime products usually depend on the reaction of lime with a fine-grained siliceous (pozzolanic) material and water to produce a concrete-like solid (sometimes referred to as a pozzolanic concrete). The most common pozzolanic materials used in waste treatment are fly ash, ground blast-furnace slag, and cement-kiln dust. All of these materials are themselves waste products with little or no commercial value at this time. The use of these waste products to consolidate another waste is often advantageous to the processor, who can treat two waste products at the same time. For example, the production of a pozzolanic reaction with power plant fly ash permits the flue gas cleaning sludge to be combined with the normal fly ash output and lime (along with other additives) to produce an easily handled solid. Many, if not all, of the comments associated with the cement systems apply to the pozzolanic systems.

Many pozzolanic processes incorporate proprietary mixtures and operations, but all are based upon the same principle of creating a siliceous material from a waste stream. Typical processes employ the mixture of the pozzolanic agents with the wastes and water (if necessary to increase the moisture content).

Waste Inputs [1,5]

Most inorganic wastes can be stabilized using lime-based pozzolanic methods. Moderate levels of organic wastes, oils and grease may be compatible with pozzolanic chemistry. Excessive fractions of volatile organics, oils, tars, and some salt compounds may inhibit the pozzolanic reactions. Appropriate for the stabilization of the following wastes (by UCD classification): 111-113; 121-123; 131-133; 141-143; 151-152; 165; 248; 251; 282-286; 417; 431; 433; 441-443; 445; 447; 518.

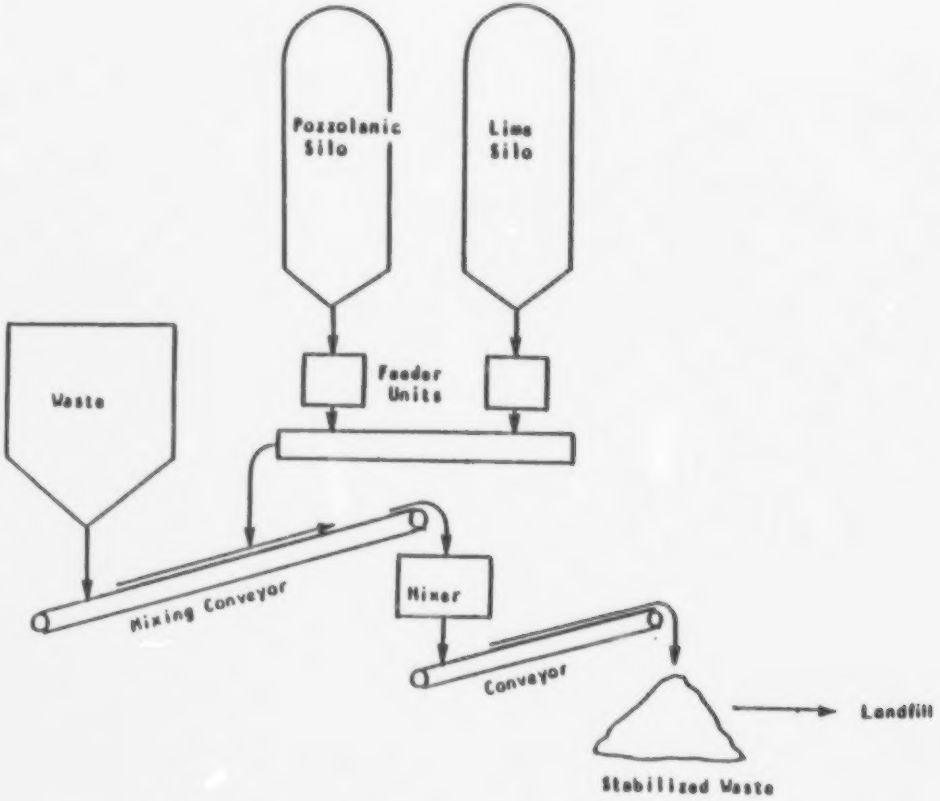

Pozzolanic Silo
Lime Silo
Waste
Feeder Units
Mixing Conveyor
Mixer
Conveyor
Stabilized Waste
Landfill

FIGURE 3.5.2 : LIME BASED (POZZOLANIC) STABILIZATION PROCESS

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1980

Effluent and Residuals [5]

Pozzolanic stabilization processes result in an increased weight and volume of residuals for disposal of the stabilizing additives. Pozzolanic wastes can be containerized or directly deposited into a landfill for disposal.

Implementation, Reliability [1,3,4,5]

Lime-based pozzolanic stabilization is a proven and effective method to solidify and isolate waste streams. Most inorganic hazardous wastes when mixed with pozzolanic (e.g., fly ash, clay) and lime (or cement dust), while maintaining proper moisture content and allowed to cure, will solidify and produce a solid monolithic mass. Such process is very similar in performance to the cement-based processes. Pozzolanic technology is particularly effective in stabilizing inorganic sludges and heavy metal hydroxide residues. The chemistry of lime-pozzolanic reactions is relatively well understood, and specialized equipment and labour are not necessary. This process can be applied easily into a regional waste management program.

Process Applications [1,5]

This process has been commercially applied to a wide range of hazardous wastes, including inorganic residues, waste containing heavy metals and waste mixtures containing low levels of organics and salts. The widest application of such process has been in physical/chemical stabilization of flue gas cleaning residues from coal burning power plants (fly ash and scrubber sludges). Similar to cement-based technology, the commercially available processes are marketed under proprietary and trade names.

Economic Considerations [1,5]

Both capital and operating costs are variable with current pozzolanic stabilization costs ranging from about $20-$65/tonne. These estimates exclude the costs of landfilling the stabilized wastes and depend upon the waste type and liquid content a well as the type and quantity of stabilization agents required.

Energy Requirements [1,5]

Energy requirements for lime-based pozzolanic processes are primarily electrical to run the pumps, mixers and conveyors. The additional costs of the lime and other materials could represent a significant portion of the energy costs.

Resource Recovery Potential [5]

The potential for materials recovery is not very high with lime pozzolanic stabilization. There is the potential for applying some stabilized low hazard wastes as a supplemental building or construction material.

Environmental Factors [5]

Lime based pozzolanic stabilization represents an environmentally effective hazardous waste management option. Reduced potentials for surface and groundwater contamination result from the enhanced physical and structural properties of the stabilized waste. Proper disposal methods should be followed, and care must be taken to assure the compatibility of the waste with the stabilizing agent (e.g., stabilization of many organic wastes has not been demonstrated).

Institutional Factors [5]

No unusual institutional constraints are expected from the implementation of pozzolanic approaches. Local opposition may arise from the landfilling of stabilized wastes; however, the process may be viewed positively by regulatory agencies and the public if materials handling and transportation are not problems.

THERMOPLASTIC TECHNIQUES

Process Description (Figure 3.5.3) [1]

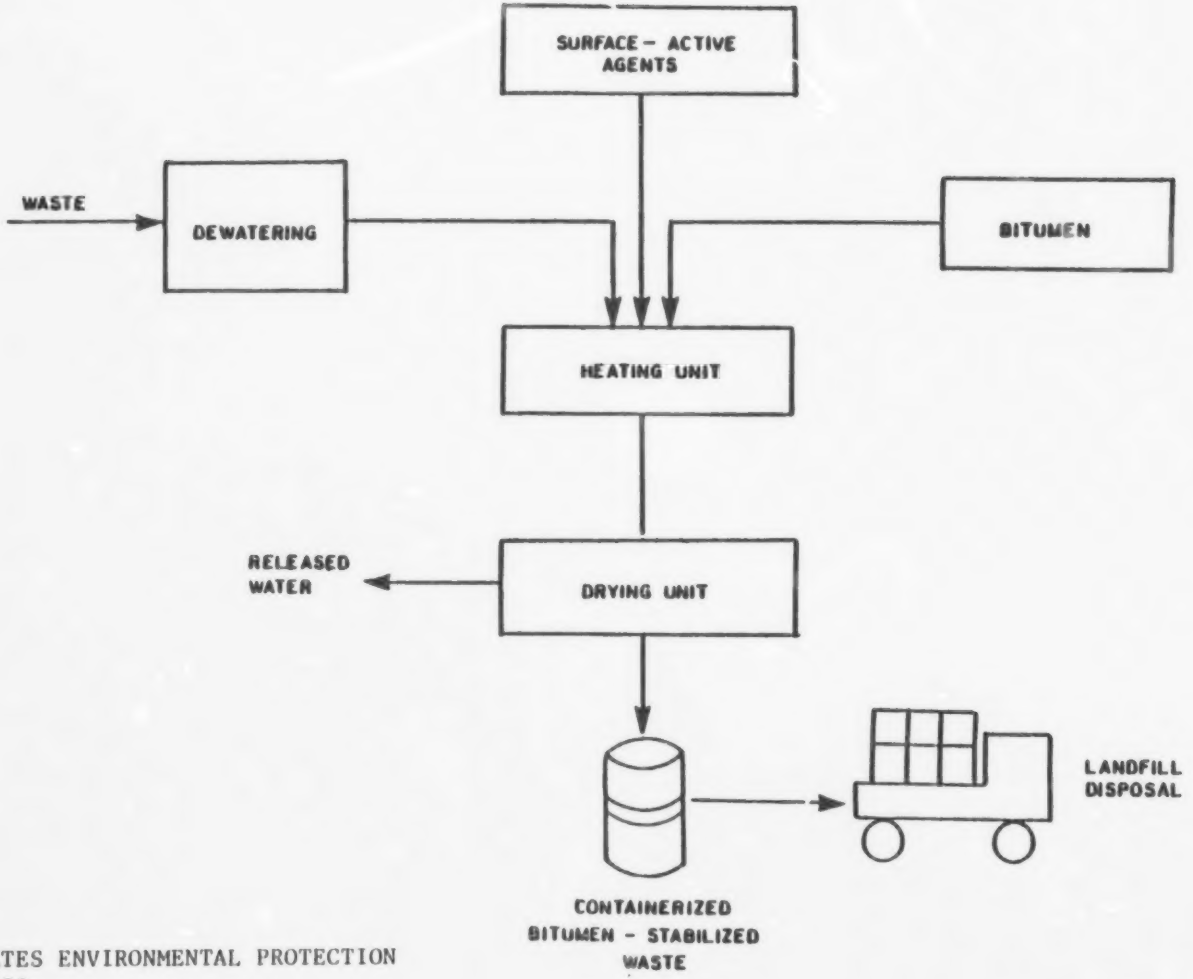
Thermoplastic stabilization techniques include the use of bitumen, paraffin and polyethylene as stabilizing agents. The use of thermoplastic solidification systems in radioactive waste disposal has led to the development of waste containment systems that can be adapted to industrial waste. In processing radioactive waste with bitumen or other thermoplastic material, the waste is dried, heated, and dispersed through a heated plastic matrix. The mixture is then cooled to solidify the mass, and it is usually buried in a secondary containment system such as a steel drum. Variations of this treatment system can use thermoplastic organic materials such as paraffin or polyethylene.

The process requires some specialized equipment to heat and mix the waste and plastic matrices, but equipment for mixing and extruding waste plastic is available. The ratio of matrix to waste is generally quite high - a 1:1 to 1:2 ratio of incorporation material to waste (on a dry-weight basis). The plastic in the dry waste must be mixed at temperatures ranging from 130°C to 230°C, depending on the melting characteristics of the material and type of equipment used.

A variation of this process uses an emulsified bitumen product that is miscible with a wet sludge. In this process, the mixing can be done at any convenient temperature below the boiling point of the mixture. The overall mass must still be heated and dried before it is suitable for disposal.

Waste Inputs [1]

The appropriate waste inputs for thermoplastic stabilization processes are variable and remain a function of the thermoplastic material. Generally, inorganic solids are candidates of this process, and in addition, some soluble salts can be mixed with the thermoplastic agents. Appropriate for stabilization of the following wastes (by UCD classification): 151-152; 165; 261-263; 431; 445; 447; 518.


SURFACE - ACTIVE AGENTS
WASTE
DEWATERING
BITUMEN
HEATING UNIT
RELEASED WATER
DRYING UNIT
LANDFILL DISPOSAL
CONTAINERIZED BITUMEN - STABILIZED WASTE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1980

FIGURE 3.5.3 : THERMOPLASTIC STABILIZATION PROCESS

Effluent and Residuals

No effluent streams result from thermoplastic techniques. The solidified mixture of waste and bituminous material become a process residue that requires containerization in drums for landfill disposal.

Implementation, Reliability

Thermoplastic techniques are proven stabilization processes for small quantities of inorganic and low level radioactive wastes. The batch-type operations work well on small waste quantities. Regional process scale-up would be difficult to achieve in a cost-effective manner. Most thermoplastic matrix materials are resistant to attack by aqueous solutions and to microbial degradation, and most matrices adhere well to the incorporated wastes.

Process Applications

Thermoplastic solidification has application to wastes not easily stabilized or treated by other processes. Organic solvents as well as strong oxidizing agents should be avoided. Primarily, inorganic solids are appropriate for use with thermoplastic techniques.

Economic Considerations [1]

Thermoplastic techniques carry high capital and operating/maintenance costs, usually an order of magnitude greater than cement or lime stabilization processes (could reach as much as $770/tonne of waste). Expensive, complicated equipment requiring specialized labour is necessary for waste processing.

Energy Requirements

Thermoplastic techniques are energy intensive because of the required melting of additives and the drying of waste materials. Additional energy is required for pumping and materials handling.

Resource Recovery Potential

Little potential exists for resource recovery, but some materials embedded in the thermoplastic matrix can be reclaimed.

Environmental Factors

Thermoplastic stabilization greatly reduces the overall waste volumes requiring disposal, and the solidified matrix reduces the solubility of materials. There exists the risk of uncontrolled combustion when working with organic materials such as bitumen at high temperatures. During heating, some mixes can release objectionable oils and odours, causing secondary air pollution.

Institutional Considerations

No unusual institutional problems result from application of thermoplastic techniques except for public objections to the transport and disposal of drum-containing wastes.

ORGANIC POLYMER PROCESSES

Process Description (Figure 3.5.4)[1,7,8]

Organic polymer techniques were developed as a response to the requirement for solidification of waste for transportation. The most thoroughly tested organic polymer solidification technique is the urea-formaldehyde (UF) system. The polymer is generally formed in a batch process where the wet or dry wastes are blended with a propolymer in a waste receptacle (steel drum) or in a specially designed mixer. When these two components are thoroughly mixed, a catalyst is added, and mixing is continued until the catalyst is thoroughly dispersed. Mixing is terminated before the polymer has formed and the resin-waste mixture is transferred to a waste container if necessary. The polymerized material does not chemically combine with the waste but rather it forms a spongy mass that traps the solid particles. Any liquid associated with the waste will remain after polymerization. The polymerized mass must often be dried before disposal.

Several organic polymer systems are available that are not based on UF resins. Dow Industrial Division is developing a vinyl ester-styrene system (Binder 101) for use with radioactive waste. Testing of this material is currently underway in the Nuclear Regulatory Commission Research Programs. The Polymeric Material Section at Washington State University has developed a polyester resin system that is being used in solidification of waste. This system is currently in a pilot-plant stage in the processing of hazardous wastes.

Organic polymer solidification processes require less treatment reagent than other systems for solidifying wastes. The waste-to-reagent mixture ratio is usually about 30% greater for a UF organic polymer system than with cement. In addition, the solidified resin is nonflammable, and high temperatures are not required in forming the resin.

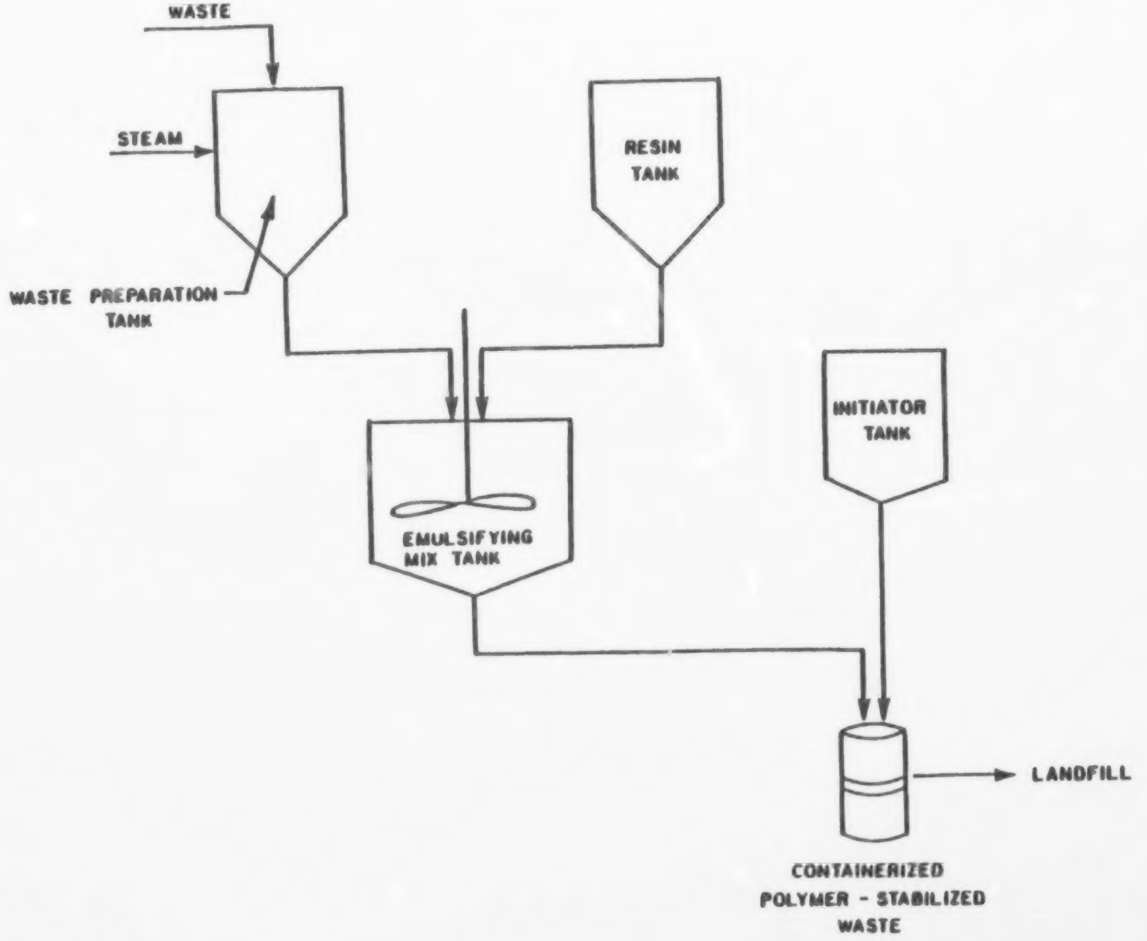

WASTE
STEAM
WASTE PREPARATION TANK
RESIN TANK
EMULSIFYING MIX TANK
INITIATOR TANK
LANDFILL
CONTAINERIZED POLYMER - STABILIZED WASTE

FIGURE 3.5.4 : ORGANIC POLYMER STABILIZATION PROCESS

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1980

Waste Inputs [1]

Organic polymer processes are suited primarily for the solidification of solid inorganic waste streams. The system requires the addition of a resin catalyst, and some organic wastes are not compatible with the process. Appropriate for stabilization of the following wastes (by UCD classification): 151-152; 165; 261-263; 431; 433; 441-443; 445; 447; 518.

Effluent and Residuals

Organic polymer processes produce no effluent streams but create a residual mixture of waste and organic resins. The solidified residue is containerized and landfilled for disposal.

Implementation, Reliability [1]

Organic polymer techniques are proven technologies for solidifying inorganic and some organic wastes. The processes have been proven effective for isolating and handling small volume of low level radioactive wastes. Containers are necessary for disposal in landfilling. Scale-up for a regional waste management approach would be difficult.

Process Applications

Organic polymer processes for batch-type stabilization operations for inorganic waste streams. In many cases, the waste types rule out use of these processes, including organic solvents and strong oxidizing salts.

Economic Considerations [1]

High capital and operating/maintenance costs are associated with organic polymer processes when compared to cement and lime based stabilization techniques. The material costs for the resin and catalyst are high. Unit costs could reach as high as $1,100/tonne of waste.

Energy Requirements

The process is not energy intensive with materials handling representing the bulk of the energy requirements. Production of the polymer process inputs is energy intensive and is reflected in the high material costs.

Resource Recovery Potential

Organic polymer stabilization processes do not provide any resource recovery potentials.

Environmental Factors [1]

Process catalysts are strongly acidic, allowing many waste materials to pass into solution. As strongly corrosive materials, some catalysts require special mixing equipment and container liners. If the process is not maintained at a pH range of 1 to 2, polymerization is incomplete, waste solids settle out, and the materials are not trapped effectively. The reaction producing the resin may release fumes that can be harmful or disagreeable even in low concentrations.

Institutional Considerations

No unusual institutional considerations are associated with organic polymer processes except for potential public objections to the handling and disposal of waste drums in chemical landfills.

GLASSIFICATION TECHNIQUES

Process Description (Figure 3.5.5) [1,2,9]

Where a waste material is extremely dangerous or radioactive, it is possible to combine the waste with silica and either fuse the material in glass or to form a synthetic silicate mineral. Glasses or crystalline silicates are leached very slowly by naturally occurring waters, so glassification waste products are generally considered to be safe materials for disposal without secondary containment. Glassification has application to highly toxic wastes. The process is designed to produce a high degree of waste containment, since glass represents an excellent isolation medium.

Waste Inputs [1]

Glassification techniques are appropriate for inorganic solids and extremely dangerous wastes. The system requires the addition of silica to act as the fixing agent. Appropriate for the solidification of the following wastes (by UCD classification): 151-152; 165; 431; 433; 441-443; 445; 447; 518.

Effluent and Residuals

No effluent stream results, but glassification processes produce a drummed matrix of molten glass/waste residuals requiring disposal.

Implementation, Reliability [1]

Glassification techniques are proven technologies with highly radioactive wastes. In general, glassification processes are assumed to produce a high degree of waste containment. The processes are batch-type, and system scale-up for a regional approach would be difficult. Specialized equipment and trained personnel are required for this process.

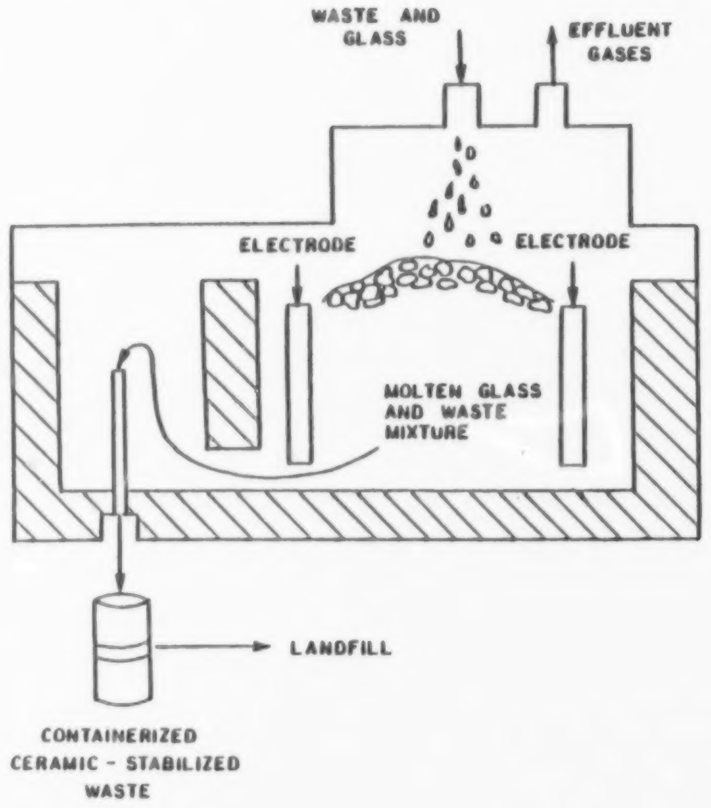

WASTE AND GLASS
EFFLUENT GASES
ELECTRODE
ELECTRODE
MOLTEN GLASS AND WASTE MIXTURE
LANDFILL
CONTAINERIZED CERAMIC - STABILIZED WASTE

FIGURE 3.5.5 : GLASSIFICATION STABILIZATION PROCESS

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1980

Process Applications

The U.S. and other countries have directed their research and development for the past 20 years toward the application of glassification to high-level liquid radioactive wastes. Glassification is viewed as an expensive but appropriate stabilization approach useful with severely hazardous inorganics or radioactive wastes.

Economic Considerations

Glassification presents high capital and operating/maintenance costs, running as high as an order of magnitude greater than lime or cement based solidification processes. Stabilizing additives may be relatively inexpensive, but energy costs are high, and specialized equipment with trained personnel are required.

Energy Requirements

Glassification processes are energy-intensive. The waste-silicate mixture must be heated up to 1350°C for melting and fusion.

Resource Recovery Potentials

There are no resource recovery potentials since the waste mixtures are tied up in a glass-silicate structure.

Environmental Factors

Overall, glassification presents less environmental threats than either thermoplastic or organic polymer processes, although long-term leaching may still create problems. Vaporization of heavy metals during the high temperature process may pose additional air emission problems.

Institutional Considerations

No unusual institutional problems result from glassification processes. In some highly toxic or radioactive waste streams, glassification may provide the only accepted disposal alternative.

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3.6 ULTIMATE DISPOSAL

INTRODUCTION [1]

Ultimate disposal technologies for hazardous waste and hazardous waste treatment residuals include:

- Secure Landfill
- Deep Well Injection
- Underground Storage
- Above Ground Storage

These disposal technologies do not treat contaminants but generally ensure that they are contained and controlled for an infinite period of time. Deep well injection has been used for many years in the oil and gas industries and is now being developed for application to wastes. Underground storage refers to the use of mines for storage of wastes; this technology is still in a developmental stage. Above ground storage incudes tankage, drums, and warehouses. This is primarily applicable to wastes which either have future recovery value or for which treatment facilities may be established in the near future.

SECURE LANDFILL

Process Description [1,2]

The secure landfill is a facility that provides long-term isolation of wastes while minimizing contaminant release to the environment. Effective isolation is achieved by sealing the major pathways by which contaminants may enter into the environment, namely by means of emissions to groundwater, surface water or air.

Secure landfilling is a rather well-defined and significantly developed technology for ultimate land disposal. Historically, landfilling has been widely applied to numerous varieties and forms of wastes on a large scale because of favourable economics. Even as regulatory requirements become more stringent and strict design criteria for secure landfills accepting hazardous wastes are developed, economics continue to favour this disposal method for certain wastes; particularly wastes that are expensive to treat further.

There are several desirable characteristics of a secure landfill:

- The site should be remote from public access and contact with surface and groundwater resources, yet be near to major waste sources and utilities. It must have sufficient capacity (several decades) to justify initial installation costs.

- The geologic setting should favour long term containment.

- Site preparation may include installation of primary and perhaps secondary liner systems; and monitoring and leachate collection.

- Operations always include proper daily intermediate and final covers to control water infiltration and air emissions, stormwater controls, accurate recording of buried wastes, etc.

- Operating plans make allowance for long-term post closure care and maintenance, including leachate collection and treatment, gas collection and handling, and monitoring.

Waste Inputs [1,2,3]

In practice, almost any kind of waste has been applied to a secure landfill. Extremely flammable, reactive wastes are avoided unless specifically pretreated to minimize risk. Solidification/stabilization and encapsulation techniques are sometimes applied to certain wastes to decrease potential leaching and make them more suitable to secure landfilling. Liquid wastes are excluded to minimize leachate generation. Radioactive wastes are not included in the OWMC mandate and hence are not in the discussion. Secure landfills are appropriate for ultimate disposal of the following wastes (by UCD classification): 151-152; 165-167; 254; 441-445; 454; 509; 512; 518; 521; 523; 531.

Effluents and Residuals

A properly located, designed, and operated secure landfill generates little leachate. This is accomplished by minimizing the amount of moisture in wastes accepted at the landfill and reducing the amount of runon entering the landfill. Leachate which is generated is collected, removed and treated at an on-site or off-site leachate (wastewater) treatment plant. The treatment process results in the generation of a residual sludge which would be handled as a special waste.

Implementation, Reliability [1]

Secure landfilling is a proven effective technology for the disposal of a wide variety of solid and semi-solid (sludge) wastes. The technology is currently being applied at several sites in North America, both by private industrial operators (chemical, steel, pharmaceutical, pesticide manufacturing, etc.) and at a regional scale.

Process Applications

Secure landfilling is applicable to a wide range of special wastes as evidenced by several successful sites currently operating. Secure landfills are also useful as a final disposal technology for the residuals from other waste treatment activities, and always only as a last resort.

Economic Considerations [4]

The costs of a secure landfill are substantial; however, in comparison to some other final disposal technologies, they are low. Capital costs include land acquisition and installation of active liners if needed and leachate collection and treatment. Currently, the average price is about $110 per tonne of waste disposed.

Energy Requirements [5]

In general, landfilling is not an energy intensive operation. For a secure landfill, energy requirements include fuel for vehicles and energy for any waste conditioning (minimal) and collection and treatment of leachate. Current costs are about $11 per tonne of waste disposal.

Resource Recovery Potential

Landfilling is usually regarded as a means of final and last resort disposal; and, therefore, resource recovery would not be applicable. If, however, careful records of waste placement within the secure landfill are kept, all buried materials would be available for future resource recovery. This might be attractive if more advanced technologies are developed and the wastes do not undergo significant degradation.

Environmental Factors

A properly designed, constructed, and operated secure landfill poses a minimal threat to the environment. Major environmental concerns during operation concern potential spills of hazardous waste. Good management practice and emergency response planning is necessary to address this concern.

DEEP WELL INJECTION

Process Description (Figure 3.6.1) [5]

Deep well injection involves the disposal of pumpable wastes below the ground to depths ranging from 300 to 3,600 meters. Wastes are usually pretreated to remove large solids that could potentially clog the injection pumps. The raw or pretreated wastes are pumped into the pores of deep permeable subsurface strata, and local geological factors determine pumping depths and characteristics. Deep well injection is a relatively new process introduced in the early 1950's, but the technology is well developed in the oil and gas industries. In Ontario, the Cambrian formation is thought to be the only suitable one for possible siting of deep well injection.

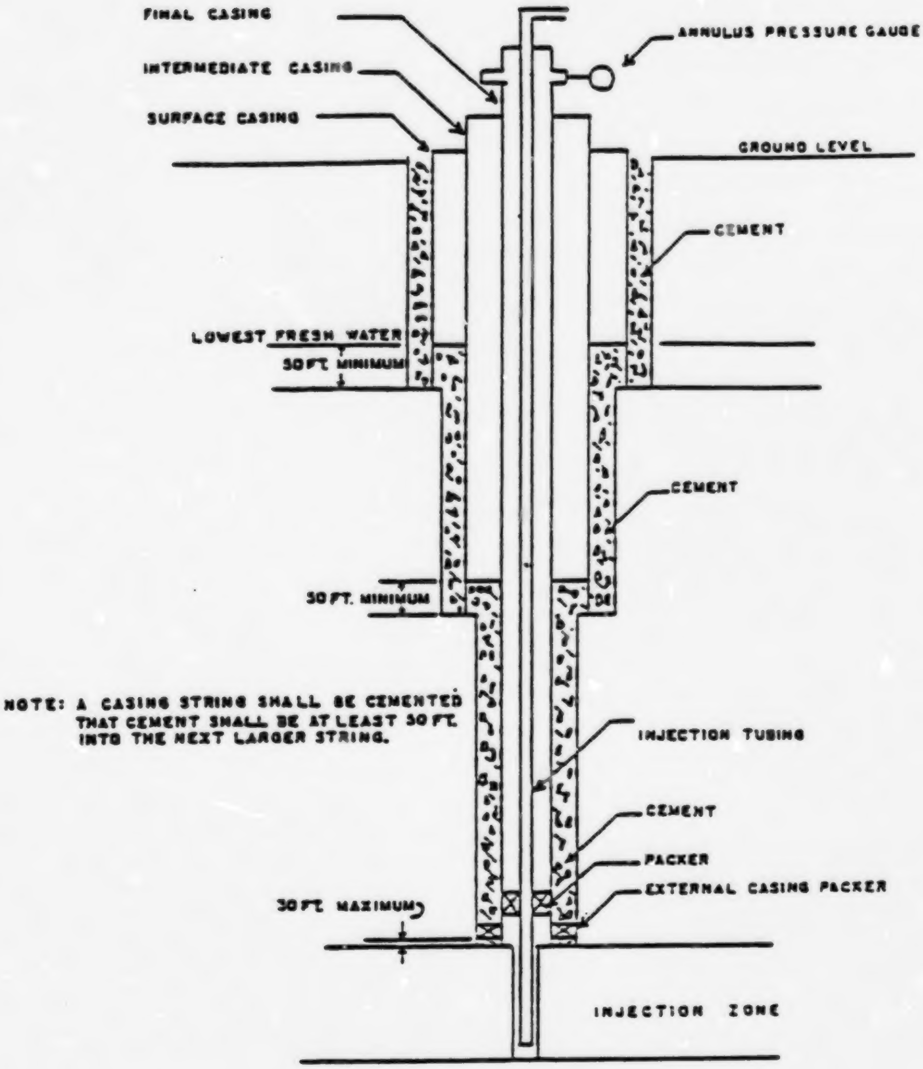
Early operators of major oil fields developed deep well injection to dispose of the contaminated brines produced during drilling operations. The now common practice of injecting salt water wastes back into the subsurface reservoirs has been identified as an avenue for potential contamination of fresh water aquifers. Deep well injection may have an application in areas where the receiving aquifer is already highly contaminated and is of little or no value.

Waste Inputs [5]

Liquid industrial wastes predominantly of low solids content are appropriate for disposal using deep well injection. These wastes include acids, bases, alcohols, solvents and salts. Appropriate for ultimate disposal of the following waste streams (by UCD classification): 111-113; 121-123; 243-245; 513.

Effluent and Residuals

Deep well injection represents an ultimate disposal technology for certain liquid waste streams. Pretreatments using pH control and filtration may produce solid residuals requiring ultimate disposal in a secure landfill.


FINAL CASING
INTERMEDIATE CASING
SURFACE CASING
ANNULUS PRESSURE GAUGE
GROUND LEVEL
CEMENT
LOWEST FRESH WATER
30 FT. MINIMUM
CEMENT
30 FT. MINIMUM
INJECTION TUBING
CEMENT
PACKER
EXTERNAL CASING PACKER
30 FT. MAXIMUM
INJECTION ZONE

NOTE: A CASING STRING SHALL BE CEMENTED THAT CEMENT SHALL BE AT LEAST 30 FT. INTO THE NEXT LARGER STRING.

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1977

FIGURE 3.6.1 :COMPLETION RECOMMENDED FOR MAXIMUM PROTECTION DURING WASTE INJECTION DEEP WELL INJECTION

Implementation, Reliability [5]

Deep well injection is a proven effective technology for the disposal of certain liquid waste streams. High pressure injection pumps have been used for over 30 years to pump oil and gas industry waste brine back into the deep subsurface strata from which the oil was removed. The technology is currently being applied by the chemical, petrochemical, pharmaceutical, oil refining, natural gas and metal processing industries to permanently dispose of their waste streams. Deep well injection can be applied on a regional waste management scale.

Process Applications [5]

Deep well injection has application as a disposal option for small volumes of liquid, hard-to-treat toxic wastes. The number of injection wells for waste disposal has increased steadily over the past 30 years, and applications are expected to grow beyond its present levels to handle a wide range of industrial wastes.

Economic Considerations [5]

The cost of producing and operating a deep well injection system is high and is economically justified only with large volumes of wastes. Capital costs for installation have ranged from $300,000 to $700,000 with annual operating costs of $30,000 to $130,000. Factors that determine the economics of deep well systems include depth to injection zone, injection rate, required pretreat ment, power costs, labour costs and drilling costs.

Energy Requirements

Deep well injection systems are energy intensive ultimate disposal processes. High energy requirements exist mainly for power to run the necessary pumps and injection equipment.

Environmental Factors[5]

Deep well injection may pose potentially high environmental implications when toxic wastes are pumped into subsurface reservoirs. Many of the wastes that are currently deep well injected pose unknown hazard potentials to the quality of aquifers and public health. Many chemicals are considered unsafe for deep well injection based upon toxicological data, degradability, environmental persistence, water solubility, compatibility reactions and corrosiveness. There is also no real control over lateral extent of flow of the waste after injection.

Institutional Considerations

Institutional problems may be extensive with application of deep well injection systems. The legal aspects of its use are still evolving, since deep well injection may be considered a desirable social activity. However, there is a school of thought requiring industries to bear the environmental costs of its use. Public acceptance has been and is a problem.

The federal government has guidelines governing the use and placing of deep wells for the purpose of the disposal of waste.

UNDERGROUND STORAGE IN GEOLOGIC FORMATIONS

Process Description (Figure 3.6.2)[6]

Storage in underground mines represents an environmentally acceptable method of managing special wastes, provided that adequate care is taken during site selection, containerization and waste handling. The practice of using salt mines and other geologic formations to store and securely isolate many industrial waste products has existed for over 40 years. Salt, potash and gypsum mines or deposits are becoming increasingly attractive for safe, long-term isolation of environmentally harmful substances. Recently, salt deposits have been used as a repository for low-level radioactive wastes, and increasing attention has been given to their application to high-level nuclear waste storage and extremely hazardous chemical warfare munitions.

To assure environmental isolation, basic underground storage criteria are recognized, including geologic stability in and around the proposed underground formation, hydrologic and surface isolation, chemical compatibility of the stored wastes with each other and with the geologic medium, personnel safety underground and long-term operational flexibility to meet changing conditions. Mined openings in salt deposits are typically large, nearly horizontal and relatively stable. To insure against waste migration, compatible waste groups can be segregated in specific mine areas, bulkheads and other special isolation techniques can be incorporated, and encapsulation or contamination processes can be used.

Waste Inputs[6]

Underground storage has application to a wide variety of solid/sludge treated waste streams. Waste treatment and containerization are recommended or required for many waste types prior to disposal. If treatment is not incorporated, compatibility of the waste with the geologic medium must be proven. Appropriate for ultimate disposal of the following wastes (by UCD classification): 151-152; 165; 167; 241-245; 248; 251; 254; 441-443; 445-447; 453-454; 513; 518; 523.

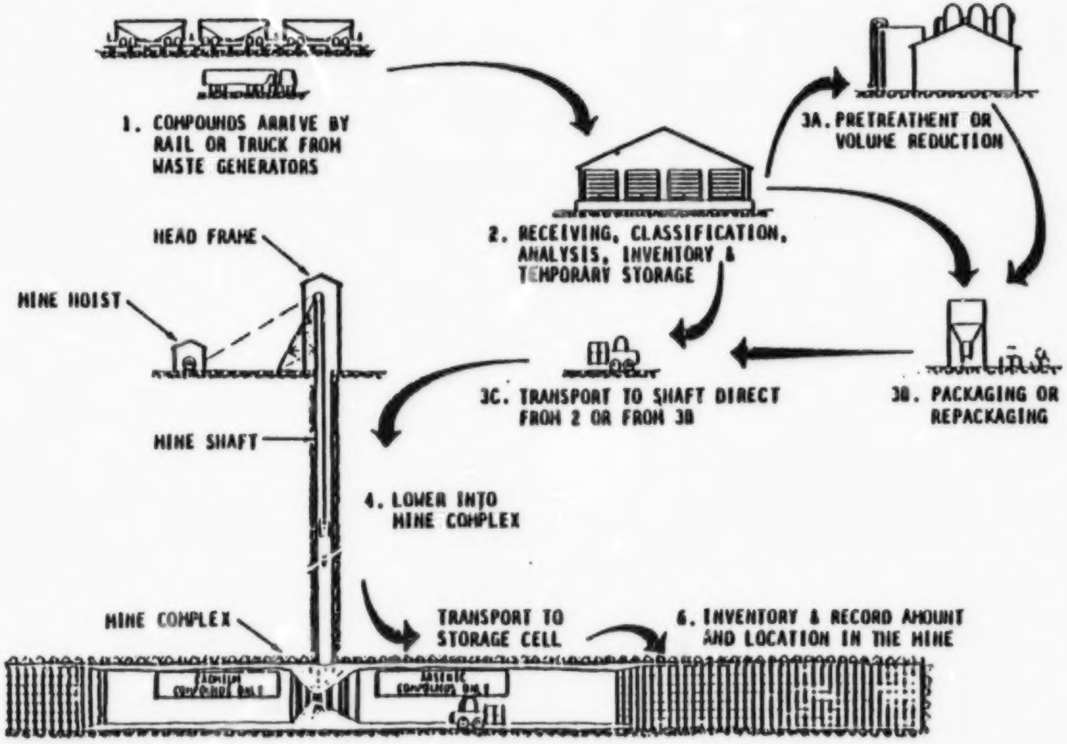

1. COMPOUNDS ARRIVE BY RAIL OR TRUCK FROM WASTE GENERATORS
2. RECEIVING, CLASSIFICATION, ANALYSIS, INVENTORY & TEMPORARY STORAGE
3A. PRETREATMENT OR VOLUME REDUCTION
3B. PACKAGING OR REPACKAGING
3C. TRANSPORT TO SHAFT DIRECT FROM 2 OR FROM 3B
HEAD FRAME
MINE HOIST
MINE SHAFT
4. LOWER INTO MINE COMPLEX
MINE COMPLEX
TRANSPORT TO STORAGE CELL
6. INVENTORY & RECORD AMOUNT AND LOCATION IN THE MINE
CADMIUM COMPOUNDS ONLY
ARSENIC COMPOUNDS ONLY

FIGURE 3.6.2 : WASTE HANDLING FLOW CHART - UNDERGROUND STORAGE

SOURCE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY, 1975

Effluent and Residuals

Underground storage in geological formations does not directly produce an effluent stream, and the process residue is simply the stored waste stream itself.

Implementation, Reliability [6]

Underground storage remains in the developmental stage in the United States and Canada, while the only known fully operational facility is in West Germany. Long-term secure storage in underground geological formations, such as salt deposits, provides a potential ultimate disposal method for long-term storage of industrial wastes. Wastes destined for ultimate disposal in an underground geological formation should be containerized and treated when necessary before placement in the mine. Storage in salt formations can be incorporated into a regional management program for Ontario provided waste compatibility is established and adequate salt deposits exist.

Process Applications [6]

The first commercial attempt to store special wastes on a large scale was in West Germany. The use of geologic formations for the storage of high-level radioactive wastes as well as toxic wastes has received significant attention in the United States. Isolation in salt formations and basalt deposits are under investigation, but no commercial facility operates at the present time.

Economic Considerations [4]

With no operational economic information available, it is difficult to draw conclusions about the cost effectiveness of underground storage. A 1977 cost assessment of underground storage revealed potential waste management fees ranging from $300-450 per tonne of waste disposed. Activated disposal costs may be as high as $1,100/tonne.

Energy Requirements

Underground storage is not an energy-intensive operation, but no quantitative information is available.

Resource Recovery Potential

Retrieval of stored containerized wastes is possible as long as materials recovery is cost effective. Underground storage will not improve or hinder the resource recovery potentials of the containerized wastes.

ABOVE-GROUND STORAGE [1,3]

The use of above-ground or retrievable storage may represent a viable ultimate disposal alternative for the management of certain wastes. Retrievable storage describes a secure system for the long-term storage of wastes prior to recycling, treatment, or destruction. Such a system provides an alternative for those wastes which have been determined to be unsuitable for landfills, but for which no economically viable treatment technology currently exists. There are several characteristics of an acceptable retrievable storage system:

- The system will provide for the safe storage of the wastes.
- The system will have sufficient capacity to accept large quantities of the waste without endangering the equipment or personnel.
- The system will be equipped to allow for the easy removal of the wastes when treatment becomes available.

Retrievable storage systems can include tanks, drums, or for certain non-volatile wastes, ponds which are equipped with liners. There are well-accepted industrial design standards for storing different types of liquids in tanks. The tanks most often used for storing liquid hazardous wastes are atmospheric tanks with either fixed or floating roofs. Low pressure tanks are used to store liquids having a vapor pressure between 3.5 and 100 kPa at normal storage temperatures. These tanks are equipped with venting systems to allow for controlled volatilization of the contents.

Waste Inputs [1]

Retrievable storage in above-ground facilities can have application to a wide range of waste streams. Liquids and slurries can be impounded or stored in tanks, and solids can be containerized and stored in engineered structures. Appropriate for ultimate disposal of the following wastes (by UCD classification): 111-113; 121-123; 131-133; 141-147; 151-152; 165; 167; 211-217; 221-228; 241-245; 251-254; 261-264; 281-289; 416-417; 431; 433; 441-443; 445-447; 454; 509-513; 518; 521; 523; 531-532.

Effluent and Residuals [1]

As an ultimate disposal technology, a properly engineered retrievable storage facility will be designed to produce no effluent or residue.

Implementation, Reliability

The technologies for application of long-term retrievable storage currently exist but have not been implemented on a regional scale for waste management. The use of long-term above-ground storage facilities for wastes implies the necessity of perpetual maintenance or care. Adequately engineered designs are possible, but insufficient practical experience presently exists with the application of this ultimate disposal technology. To properly dispose of waste drums and containers, the building must be constructed to avoid contact of the wastes with the outside environment, and the roof, walls and floor must provide isolation from rainwater and must provide containment of the waste material. Floors and curbing should be constructed of continuous and impervious materials to minimize waste penetration. Long-term maintenance of impoundments or lagoons is required. Waste liners must be compatible with the contained wastes and have a low permeability over an extended period of time.

Process Applications [1]

Retrievable storage in above-ground facilities has application in waste management to those wastes which may have marginal current economic value or may present increased future resource recovery potentials. Any waste type can be stored (liquids, slurries, sludges or solids) as long as the necessary engineering precautions are taken and the potentially high operational costs are maintained. Retrievable storage may be required for any untreated waste which presents a health hazard if disposed in a chemical landfill. To date, the concept has been applied to the long-term storage of PCB wastes. As additional chemicals are found to be inappropriate for landfill disposal, retrievable storage will become an important option for waste generation.

Environmental Concerns [1]

Accidental spills and fires are the areas of environmental concern related to retrievable storage. These concerns, similar to concerns related to any chemical storage system, must be addressed. There is a widely known and accepted set of standards regarding the design and operation of storage facilities. These standards are endorsed by many professional associations and have been incorporated into the U.S. RCRA regulations. Adherence to these design guidelines will minimize the change of operational failure. Additionally, good management practice requires:

- A strict policy to separate reactive and flammable chemicals from toxics
- A significant buffer zone around sites
- Available emergency response capability to deal with spills.

Concern over the risks presented by retrievable storage must be balanced against the risk of groundwater contamination presented by landfill disposal.

Institutional Considerations

The organization of long-term maintenance and monitoring could present institutional difficulties. Political concerns in locating a waste facility must also be recognized.

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APPENDIX A

TYPICAL WASTE STREAMS AND RESIDUALS BY UCD CATEGORY

UCD WASTE	DESCRIPTION	TYPICAL WASTES	MOE CLASS.
111	Acidic Solution with Heavy Metals	Pickle Liquor Rinse Water	101
112	Acidic Solution with Other Metals and Non-Metals	Demineralizer Regenerant	101
113	Other Acidic Solutions	Boiler Stack Scrubber Water with Dilute Carbonic Acid (H_2CO_3)	101
121	Alkaline Solution with Heavy Metals	Rinse Waters from Surface Cleaning of Metals	102
122	Alkaline Solutions with Heavy Metals	Demineralizer Regenerant	102
123	Other Alkaline Solutions	Cleanup Water from Lime or Cement Kiln	103
131	Spend Etchant/Plating Solutions, Acid	Ammonia Based, Containing Copper, Tin, Lead or Cadmium	103
132	Spent Etchant Plating Solution, Alkaline	Contain Strong Complexing Agent and Copper, Tin, Lead and/or Cadmimum	103
133	Spent Pickle Liquor from Ferrous and Non Ferrous Metals	Strong Acids with Iron, Fluroide, Hydrochloric Acid (HCl), Sulfuric Acid (H_2SO_4), Nitric Acid (HNO_3)	101
141	Aqueous Solutions with Heavy Metals	Cleaning Solutions from Tanks, Trucks, or Railroad Tankers	190
142	Aqueous Solutions with Other Metals	Rinse Water from Heat Treating Salt Baths, Contain Barium, Aluminum	190
143	Aqueous Solutions with Reactive Anions	Bleaching Solutions Containing Sulfite, Chlorite, Fluoride, Bromate	190
145	Brine	Salt Solutions After Neutralization or Chlor/Alkali Productions	190

APPENDIX A (CONTINUED)

UCD WASTE	DESCRIPTION	TYPICAL WASTES	MOE CLASS.
146	Solution Containing Cyanide	Plating Baths	104
147	Solution Containing Sulfides	Plating Baths	190
151	Inorganic Solids	Foundry Sand	190
152	Inorganic Solid Chemicals	Aged or Off Spec. Chemicals including Lime, Caustic Soda and Partial Containers of Laboratory Size	190
165	Spent Catalyst	Maybe Carbon or Metal	None
167	Other Inorganic Waste	Ash and Construction Residue	None
211	Halogenated Solvents with Heavy Metals	Methylene Chloride, 1, 1, 1 Trichloroethylene Used for Metal Cleaning	204
212	Halogenated Solvents with Other Metals	Surface Cleaning and Degreasing Solvents	204
213	Halogenated Solvents	Freon and Other Solvents Used in Chemical Processing	204
214	Non-Halogenated Solvents with Heavy Metals	Toluene, Benzene, Xylene Contaminated with Catalysts	203
215	Non-Halogenated Solvents with Other Metals	Acetone, Methylisobutylketone (MIBK) used in Paint & Varnish Formulation	203
216	Non-Halogenated Solvents	Methylethylketone (MEK) Solvents Contaminated with Dirt	203
217	Unspecified Solvents	Alcohols and Mixtures of Solvents	203
221	Organic Liquids with Metals and Halogens	Dyes	290

APPENDIX A (CONTINUED)

UCD WASTE	DESCRIPTION	TYPICAL WASTES	MOE CLASS.
222	Organic Liquids with Halogens Only	Chloroform, Carbon Tetrachloride	290
223	Organic Liquids with Metals Only	Nickelcarbonyl, Methyl Mercury	290
224	Other Organic Liquids	Creosote and Other Polyaromatic Hydrocarbons	206
225	Aqueous Solution with Than non-Halogenated Residues Less 10%	Laboratory Mixtures	290
226	Aqueous Solutions with Halogenated Residues Less Than 10%	Waste or Rinse Waters After Degreasing	290
227	Aqueous Solution with Non-Halogenated Organic Residue Greater Than 10%	Laboratory Mixtures	290
228	Aqueous Solution with Halogenated Organic Residue Greater than 10%	Wash or Rinse Waters after Degreasing	190
241	Pesticides and Wastes	Partial Containers, Tank Washings, Off Spec. Product, etc.	302
242	PCB Oils and High Strength (over 500 ppm) Liquids	From Transformers and Capacitors	209
243	Pharmaceuticals and Waste	Off-Spec. Drugs, Cleanup Waters, etc., Includes Items such as Vitamins	304
244	Photochemicals and Waste	Most Solutions Non-Toxic Except those with Silver	190
245	Off-Spec or Aged Organics	Can Include Solids or Liquids. Generally in Containers	290

APPENDIX A (CONTINUED)

UCD WASTE	DESCRIPTION	TYPICAL WASTES	MOE CLASS.
247	Halogenated Still Bottoms	Spent Solvent or Waste Oil Recovery	290
248	Non-Halogenated Still Bottoms	Solvent Recovery Operations	290
251	Tannery Wastes	Solutions with Hexavalent Chrom-line, Alkaline Solutions	190/ 290
252	Solid or Sludge Tannery Wastes	Leather Shavings with Chrome, Other Sludge	190/ 290
254	Adhesives or Glue	Waste Glues including Some Urea-Formaldehyde Waste. Some May have Phenol and Most are Aqueous. Solids are Non-Hazardous	301
257	Phenolic Wastes	Phenolic Oil, Toluene Diisocyanide Residue	208
258	Waste Tar and Residues		202
261	Polymeric Resin	Polyester, Urethane, Etc.	205
262	Latex Wastes	Cleanup Water, Paint, Latex and Acrylic Resins	205
263	Other Polymeric Wastes	Cleanup, Kettle Bottoms, Thermoplastic Resins, Etc.	205
264	Thermoset Wastes	Urea-Formaldehyde and Thermoset Wastes	205
281	Waste Oil and Mixed Oil	Used Automotive Oil, Cutting Oil - May Contain Solvents or Metals	202
282	Oily Tank Bottoms	Crude Oil or Sludge from Storage	

APPENDIX A (CONTINUED)

UCD WASTE	DESCRIPTION	TYPICAL WASTES	MOE CLASS.
283	Oily Mud, Sediment and Water	Crude Oil Tanker Cleaning	201
284	Oily Acidic Solids	Solids Which Result from Emulsion Breaking and Re-Refining	201
285	Oily Alkaline Solids	Mostly Refining Solids from Processing Line	201
286	Oil/Water Separator Sludge	Oil Cooled Heavy Inorganics	201
287	Oily Sludge	May be from Sources Other than Oil Processing, etc. Foods and Rendering	201
288	Oily Wastes with Heavy Metal Contaminants	Steel Rolling Mill Sludges and Mill Scale	201
289	Oily Wastes with Water	Emulsions, Cleanup Water from Garages, Cooling Waters	201
416	Ink Sludge	Sludge Could Contain Solvents, and Lead, Cesium, Chromium	301
417	Alum and Gypsum Sludges	Waste Water Phosphate Removal Sludge	
431	Heavy Metal Sludge	Similar to that in 113, 141.	402
433	Other Metal Sludges	Ferric Chloride, Aluminum Oxide, etc.	402
441	Lime Sludges	From Treatment of Acids and Bases, Similar to 431	402
443	Sulphur Sludge	Desulphurization of Flue Gas Nonreactive but Very Low Bearing Strength	402

APPENDIX A (CONTINUED)

UCD WASTE	DESCRIPTION	TYPICAL WASTES	MOE CLASS.
444	Cyanide Bearing Sludge	Pot Liners from Aluminum Reduction and Scrubber Sludge from Blast Furnace	402
445	Plating or Metal Finishing Sludge	From Treatment of Metal Contaminated Solutions	402
446	Degreasing Sludge	Grease and Oily Soil containing Trichloroethane (TCE)	290
447	Tetraethyl Lead Sludge	Tank Bottoms	290
454	Paint Sludge	Drum Bottoms, Spills, Cleanup, etc.	301
455	Paint Sludge without Heavy Metals	Mostly Latex.	301
509	Gas Cylinders or Containers	Oxygen Cylinders - Empty	
512	Spill Cleanup	Oil/Soil Mixture	402
513	Laboratory Waste Chemicals	Partially Full Small Containers	790/ 290
518	Dust Collector Wastes	Dry Lime from Dust Control Baghouse	
521	Spent Cartridge Filters	Air Cleaning Filters on Ventilation System	
523	Tank Bottom Sediments	Some may Contain Flammable Organics	
528	Pathogenic Wastes	Hospital Used Bandages, and Dressings	
529	Explosive Wastes	Red Mud from Munitions Manufacture	
531	Contaminated Rags	Cleanup Materials	
532	Equipment and/or Containers Contaminated with Pesticides	Empty Pesticide Cans	201

MINISTRY OF THE ENVIRONMENT LIW WASTE CLASSIFICATION SYSTEM

101	Acids
102	Alkalis
103	Metal Finishing Wastes
104	Cyanides
105	Chemical Fertilizer Wastes
106	Phosphates
190	Other Inorganic Wastes
201	Oily Wastes
202	Waste Oils
203	Organic Solvents
204	Chlorinated Solvents
205	Plastic Resins
206	Amines
207	Glycols
208	Phenols
209	PCB's
290	Other Organic Wastes
301	Pigments, Paints, Printing and Adhesives
302	Pesticides
303	Detergents, Cleaners and Soaps
304	Pharmaceutical and Cosmetics
401	Plant and Animal Wastes
402	Inert Sludges

APPENDIX B

GLOSSARY OF TERMS

A

ACID WASTE A primarily aqueous waste resulting from the separation of solids. The aqueous portion or effluent is normally discharged to a sewer or directly to a wastewater treatment plant for treatment.

ACTIVATED SLUDGE PROCESS A process by which bacteria that feed on organic wastes are continuously circulated and put in contact with organic waste in the presence of oxygen. Incoming wastewater is mixed with recycled activated sludge and the mixture is aerated, allowing various oxidation reactions to take place that remove much of the organic waste from wastewaters. This has been used for treatment of refinery, petrochemical and biodegradable organic wastewaters.

ADSORPTION The adnerence of a substance to the surface of another solid or liquid substance.

AERATED LAGOON Speeds up the natural process of the biological decomposition through the stimulation of bacteria to degrade organic wastes. The process requires a basin of significant depth (usually 1.2 to 5.2m), and introduces oxygen into the pond through mechanical or diffused aeration equipment. Aerated lagoons have been used successfully as an economical means to treat industrial wastes where high quality effluents are not required.

AERATION The act of exposing a liquid to air (oxygen) with the aim of producing a high level of dissolved oxygen in the liquid.

AFTERBURNER An air pollution control device that removes undesirable organic gases by incineration.

ALKALI WASTE Corrosive liquid waste, such as lye, with a pH less than or equal to 12.5

APPENDIX B (CONTINUED)

AQUEOUS WASTE Relating to or having the characteristics of water.

AQUIFER Means a geologic formation, group of formations, or part of a formation that is capable of yielding useable quantities of groundwater to wells or springs.

B

BASIN Means any uncovered device constructed of artifical materials used to retain wastes as part of a treatment process, usually with a capacity of less than $400m^3$. Examples of basins include open mixing tanks, clarifiers, and open settling tanks.

BIOCHEMICAL OXYGEN DEMAND (BOD) (1) The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time under specified conditions. (2) A standard test used in assessing wastewater strength.

BIODEGRADABLE any substance that decomposes quickly through the action of microorganisms.

BIOLOGICAL WASTEWATER TREATMENT A type of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Intermittent sand filters, contact beds, trickling filters, and activated sludge tanks are examples of the equipment used.

BOTTOM ASH The non-airborne combustion residue from burning pulverized coal in a boiler. The material falls to the bottom of the boiler and is removed mechanically.

C

CAKE The solids discharged from a dewatering apparatus.

APPENDIX B (CONTINUED)

CELL Means a portion of waste in a landfill which is isolated horizontally and vertically from other portions of waste in the landfill by means of a soil barrier which meets criteria specified.

CHEMICAL FIXATION Means the treatment process involving reactions between the waste and certain chemicals, resulting in solids which encapsulate, immobilize or otherwise tie up hazardous components in the waste so as to minimize the leaching of hazardous components and render the waste nonhazardous or more suitable for disposal.

CHEMICAL OXYGEN DEMAND (COD) a measure of the oxygen required to oxidize all compounds in water, organic and inorganic.

CHEMICAL PRECIPITATION (1) Precipitation induced by addition of chemicals. (2) The process of softening waters by the addition of lime or lime and soda ash as the precipitants. (See Precipitation)

CLARIFICATION Any process or combination of processes, the primary purpose of which is to reduce the concentration of suspended matter in a liquid.

COAGULATION In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

COMBUSTION ZONE Means that portion of the internal capacity of an incinerator where the gas temperatures of the materials being burned are within 100°C of the specified operating temperature.

COMPOSTING An aerobic process involving the biological stabilization of sludge by micro-organisms. Generally comprises spreading or windrowing the material sometimes mixed with a bulking agent to maximize air contact.

APPENDIX B (CONTINUED)

CONCENTRATION The relative fraction of one substance in another, normally expressed in weight percent, volume percent or as weight/volume.

CONTAINER Means any portable enclosure in which a material can be stored, handled, transported, treated, or disposed.

CONTAMINANT Means any physical, chemical, biological or radiological substance or matter in water. "Contaminant" includes, but is not limited to or by, the term pollutant.

CONTAMINATION The degradation of natural water, air, or soil quality as a result of man's activities, to the extent that its usefulness is impaired.

CORROSIVE WASTE Is an aqueous solution with a pH less than or equal to 3, or greater than or equal to 12, or a material that corrodes steel at a rate of 0.6 cm year at 55°C.

CORROSIVITY Tending or having the power to wear away gradually by chemical action; usually has a very high or very low pH value. May cause skin damage on contact.

D

DEEP-WELL INJECTION Disposal of raw or treated hazardous wastes by pumping wastes into deep wells for filtration through porous or permeable subsurface rock.

DEWATERING A physical process which removes sufficient water from sludge so that its physical form is changed from essentially that of a fluid to that of a slurry

APPENDIX B (CONTINUED)

or damp solid. Some major types of equiment used are: Rotary Vacuum Filters, Centrifuges, Drying Beds, Filter Presses, Horizontal Belt Filters, Rotating Cylindrical Devices, Lagoons, etc.

DISCHARGE The release of any waste stream or any constituent thereof to the environment.

DISPOSAL Means the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters.

DISPOSAL FACILITY Means any Hazardous Waste Management facility which disposes of hazardous waste.

E

ELECTROSTATIC PRECIPITATOR A device that collects particulates by placing an electrical charge on them and attracting them onto a collecting electrode. When installed in resource recovery plants they significantly reduce polluting air emissions.

ENERGY RECOVERY Obtaining energy from solid waste through any of a variety of processes.

ENVIRONMENTAL PROTECTION AGENCY (EPA) is the US federal government agency responsible for environmental matters.

APPENDIX B (CONTINUED)

F

FACILITY Means any land and appurtenances, thereon and thereto, used for the treatment, storage, and/or disposal of hazardous waste.

FATS (WASTES) Triglyceride esters of fatty acids. Erroneously used as synonymous with grease.

FILTER A device for removing solid particles from a fluid stream by passing the stream through an open-structured barrier which physically restrains the larger particles from following. Examples of such barriers are woven or non-woven fabrics, woven metal wires, open-celled plastic foam, sand or gravel beds, etc. Some examples of filtering equipment include pressure or vacuum filters, filter presses, belt filters, bag houses, residential air filters, sand filters, etc.

FLUID Means material or substance which flows or moves whether semisolid, liquid, sludge or any other form or state.

FLY ASH noncombustible particles carried by flue gas.

FREEBOARD Means the vertical distance between the average maximum level of the surface of waste in a surface impoundment, basin, open tank, or other containment and the top of the dike or sides of an impoundment, basin, open tank, or other containment.

FUGITIVE EMISSIONS Means air contaminant emissions which are not planned and emanate from sources other than stacks, ducts, or vents or from non-point emission sources.

APPENDIX B (CONTINUED)

G

GENERATION The production of liquid industrial waste hazardous waste.

GENERATOR A person or firm which produces hazardous waste.

GREASE In wastewater, a group of substances including fasts, waxes, free fatty acids, calcium and magnesium soaps, mineral oils, and certain other nonfatty materials. The type of solvent and method used for extraction should be stated for quantification.

GROUNDWATER A body of water, generally within the boundaries of a watershed, which exists in the internal passageways of porous geological formations (aquifers) and which flows in response to gravitational forces. Very often the source of water for communities and industries.

H

HALOGEN Members are all nonmetals: fluorine, chlorine, bromine, iodine, and astatine. Each is an exceptionally reactive element. In their simplest compounds the halogens exhibit a valence of -1.

HAULED LIQUID INDUSTRIAL WASTE Means liquid waste, other than hauled sewage, that results from industrial processes or manufacturing or commercial operations and that is transported in a tank or other container for treatment or disposal, and includes sewage residue from sewage works that are subject to the provisions of the Ontario Water Resources Commission Act. Source: Ontario Regulation 824 (General) 1970.

APPENDIX B (CONTINUED)

HAULED SEWAGE Means waste removed from,

i. a cesspool,
ii. a septic tank system,
iii. a privy vault or privy pit,
iv. a chemical toilet,
v. a portable toilet, or
vi. a sewage hold tank.

Source: Ontario Regulation 824 (General) 1970.

HAZARDOUS WASTE A waste, or combination of wastes, which because of its quantity, concentration, toxicity, ocrrcsiveness, mutogenicity or flammability, or physical, chemical, or infectious characteristics may (1) cause, or signifcantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

HAZARDOUS WASTE MANAGEMENT Means the systematic control by collection, source separation, storage, transportation, processing, treatment, recovery, and disposal of hazardous wastes.

HEAVY METALS Metallic elements having a high density, toxic for the most part.

I

IGNITABLE WASTE Means a waste that is a liquid with a flash point below 140°F (60°C); non-liquids that are liable to cause fires through friction, absorption of moisture, spontaneous chemical changes, or retained heat, or when ignited burn so vigorously and persistantly as to create a hazard during its management.

APPENDIX B (CONTINUED)

IMPOUNDMENT Means a standing body of open water created by artificially blocking or restricting the flow or circulation of water. As used in this regulation, the term does not include artificial lakes or ponds created by excavating and/or diking dry land areas to collect and retain water for such purposes as stock watering, irrigation, settling basins, cooling, or rice growing, and actually used for such purpooses.

INCINERATION WASTE Means the residue from incineration, other than incinerator ash and fly-ash. Source: Ontario Regulation 824 (General) 1970.

INCINERATOR Means an engineered device using controlled flame combustion to thermally degrade hazardous waste. Examples of devices used for incineration include rotary kilns, fluidized beds, liquid injection incinerators, cement kilns, and utility boilers.

INCINERATOR ASH Means the ash residue, other than fly-ash, resulting from incineration where the waste is reduced to ashes containing by weight less than 10 percent of combustible materials. Source: Ontario Regulation 824 (General) 1970.

INDUSTRIAL WASTE INJECTION WELL An injection well used for the disposal of waste fluids from an industrial facility into a subsurface station.

INFECTIOUS Capable of transmitting diseases caused by pathogenic organisms (see bacteria, virus, parasite).

INORGANIC MATTER Chemical substances of mineral origin, not containing carbon to carbon bonding. Generally structured through ionic bonding.

APPENDIX B (CONTINUED)

L

LAGOON (1) A pond containing raw or partially treated wastewater in which aerobic or anerobic stabilization occurs. (2) Generally, any pond for the temporary or permanent storage of liquid.

LANDFARMING Application of waste onto land and incorporation into the surface soil for the purpose of attenuation. Synonyms include land application, land cultivation, land irrigation, land spreading, soil-farming, and soil incorporation.

LEACHATE The fluid stream which issues from a pile or cell of solid materials and which contains water, dissolved solid and decomposition products of the solids. Leachate may enter the groundwater and contaminate drinking water supplies.

LINER A relatively thin structure of natural clay, Poz-O-Tec or manufactured material (various plastics) which serve as barriers to prevent leachate from reaching or mixing with groundwater in landfills, lagoons, etc.

LIQUID Refers to wastes which are "pumpable" under normal conditions.

LIW Refers to liquid industrial waste.

M

MANIFEST Means the form used for identifying the quantity, composition, and the origin, routing, and destination of hazardous waste during its transportation from the point of generation to the point of disposal, treatment, or storage.

APPENDIX B (CONTINUED)

MICROORGANISM A living organism not discretely visible to the unaided eye. These organisms obtain nutrients from and discharge waste products (largely CO_2 or O_2) into the fluid in which they exist, thus serving to lower the nutrient level.

MIDNIGHT DUMPER An idiomatic term referring to a person who disposes of hazardous or noxious wastes in a stealthy, illegal manner.

N

NON-POINT SOURCE Means a source from which pollutants emanate in an unconfined and unchannelled manner, including, but not limited to; (1) For non-point sources of water effluent, this includes those sources which are not controllable through permits. Non-point source water pollutants are not traceable to a discrete identifiable origin, but result from natural processes, such as nonchannelled run-off, precipitation, drainage, or see page; (2) For non-point sources of air contaminant emissions, this normally includes any landfills, land-farms, surface impoundments, and basins.

O

ONTARIO WASTE MANAGEMENT CORPORATION (OWMC) is a provincial crown agency, its mandate is to implement a province-wide, long term program for the management of liquid industrial and hazardous wastes.

OFF-SITE Means any site that does not meet the definition of "on-site" as defined in this section.

ON-SITE Means on the same or geographically contiguous property. Two or more pieces of property which are geographically contiguous and are divided by public or private right(s)-of-way are considered a single site.

APPENDIX B (CONTINUED)

ORGANIC Being, containing, or relating to carbon compounds, especially in which hydrogen is attached to carbon, whether derived from living organisms or not.

OXIDATION Generally the union of a substance with oxygen (e.g., burning). Chemically increasing the positive or decreasing the negative valence of an atom or ion, or the removal of an electron from an atom or ion.

P

PATHOGENIC capable of causing disease.

PERMEABILITY The property of a solid material which allows fluid to flow through it. Usually described as a rate of penetration at a defined pressure. (Poz-O-Tee permeability: 10-7 cm/sec).

PERMITS The official approval of and permission to proceed with an activity controlled by the permitting authority. Several permits from different authorities may be required for a single operation.

pH The measure of the acidity or alkalinity of a chemical solution, from 0 to 14. The reciprocal of the logarithm of the hydrogen ion concentration. The concentration is the weight of hydrogen ions, in grams per liter of solution. Neutral water, for example, has a pH value of 7 and hydrogen ion concentration of 10-7.

POINT SOURCE Any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, or concentrated animal feeding operation from which contaminants may be discharged.

APPENDIX B (CONTINUED)

POLLUTANT Means dredged soil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water.

POST-CLOSURE CARE Means the monitoring and facility maintenance activities conducted after closure.

POTW (Publicly owned treatment works) means a treatment works owned by a municipality excluding any sewers or other conveyances not leading to a facility providing treatment.

POZZOLANIC A type of chemical reaction between a silica-alumina-containing solid and a lime-containing solid. Can produce a concrete-like structure from the separate particles.

PPM Parts per million. $(1:10^6)$

PPB Parts per billion $(1:10^9)$

PYROLYSIS The chemical decomposition of a material by heat in the absence of oxygen.

R

REACTIVE WASTE Is a material that is normally unstable and readily undergoes violent chemical change without detonating; reacts violently with water; forms potentially explosive mixtures with water; or generates toxic gases, vapors or fumes when mixed with water; is a cyanide or sulfide bearing waste which can generate toxic gases, vapors, or fumes when exposed to mild acidic or basic

APPENDIX B (CONTINUED)

conditions; is capable of explosion or detonation with a strong initiating source, when heated under confinement, or combined with water; is readily capable of detonation or explosive decomposition or reaction at normal temperatures and pressures; is a forbidden explosive, a Class A explosive or a Class B explosive.

REACTIVITY Tendency to be unstable and to readily undergo violent chemical change; may be capable of detonation or explosive reaction.

RECOVERABLE RESOURCES Materials that still have useful chemical or physical properties after serving a specific purpose and can, therefore, be reused or recycled for the same or other purposes.

RECYCLING As commonly used, means using discarded materials and objects in original or changed form rather than wasting them. Precisely used, refers to sending a material back into the process by which it was first formed.

RESIDUE Solid or semisolid materials such as, but not limited to ash, ceramics, glass, metal and organic substances remaining after incineration or processing.

RESOURCE RECOVERY The extraction of useful materials or energy from solid waste. Such materials can include paper, glass and metals which can be reprocessed to be used again. Resource recovery is usually associated with mechanical methods.

RETENTION TIME Means the time hazardous waste is subjected to the combustion zone temperature.

REUSE The utilization of a product as is or slightly refurbished, by a different person.

RUN-OFF Means that protion of precipitation that drains over land as surface flow.

APPENDIX B (CONTINUED)

S

SATURATED ZONE (Zone of Saturation) means that part of the earth's crust in which all voids are filled with water.

SCRUBBING The removal of impurities from a gas stream by spraying of a liquid.

SEMIPERMEABLE MEMBRANE A barrier, usually thin, that permits passage of particles up to a certain size or of special nature. Often used to separate colloids from their suspending liquid, as in dialysis.

SIC Stands for "Standard Industrial Code" which is a nationally recognized two to four digit number developed by the U.S. Department of Commerce that classified industries (e.g. 286 = organic chemical manufacturers) and is used to organize waste generators.

SITE Means the land or water area upon which a facility or activity is physically located or conducted, including but not limited to adjacent land used for utility systems, as repair, storage, shipping or processing areas, or other areas incident to the controlled facility or activity.

SLUDGE Means any solid, semisolid or liquid waste generated from a municipal, commercial, or industrial wastewater treatment plant, water supply treatment plant, or air pollution control facility or any other such waste having similar characteristics and effects.

SLURRY A pumpable mixture of solids and fluid.

SOLID WASTE Means any garbage, refuse, sludge from a waste treatment plan, water supply treatment plan, or air pollution control facility and other discarded

APPENDIX B (CONTINUED)

material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point sources subject to permits.

SOLVENT A substance capable of, or used in, dissolving or dispersing one or more other substances.

SPILL Means any unplanned discharge or release of hazardous waste onto or into the land, air or water or any accidental discharge of a hazardous waste into the land or water.

STORAGE When used in connection with hazardous waste, means the containment of hazardous waste, either on a temporary basis or for a period of years, in such a manner as not to constitute disposal of such hazardous waste.

T

THICKENING An increase in solids concentration, whether it occurs as the objective of a separate process, or as a secondary effect of a process provided essentially for a different purpose.

TOXICITY The ability of a material to produce injury or disease upon exposure, ingestion, inhalation, or assimilation by a living organism.

TOXIC WASTE Is a waste which when a sample of waste is subjected to certain extraction procedures outlined by the EPA contains one or more listed contaminants (arsenic, lead, mercury are examples of the listed contaminants).

APPENDIX B (CONTINUED)

TRANSFER STATION Means a waste disposal site used for the purpose of transferring waste from a collection vehicle to another carrier for transportation to another waste disposal site. Source: Ontario Regulation 824 (General) 1970.

TRANSPORTER Means a person or Federal Agency engaged in the transportation of hazardous waste by air, rail, highway or water.

TRICKLING FILTER a biological treatment device: wastewater is trickled over a bed of stones covered with bacterial growth.

TREATED AREA OF A LANDFARM Means that protion of a landfarm that has had hazardous waste applied to it, to include the zone of incorporation.

TREATMENT When used in connection with hazardous waste, means any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste non-hazardous, safer for transport, amenable for recovery, amenable for storage, or reduced in volume. Such term includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it nonhazardous.

U

UCD Stands for "University of California at Davis" and represents a classification system for liquid industrial wastes and hazardous wastes.

APPENDIX B (CONTINUED)

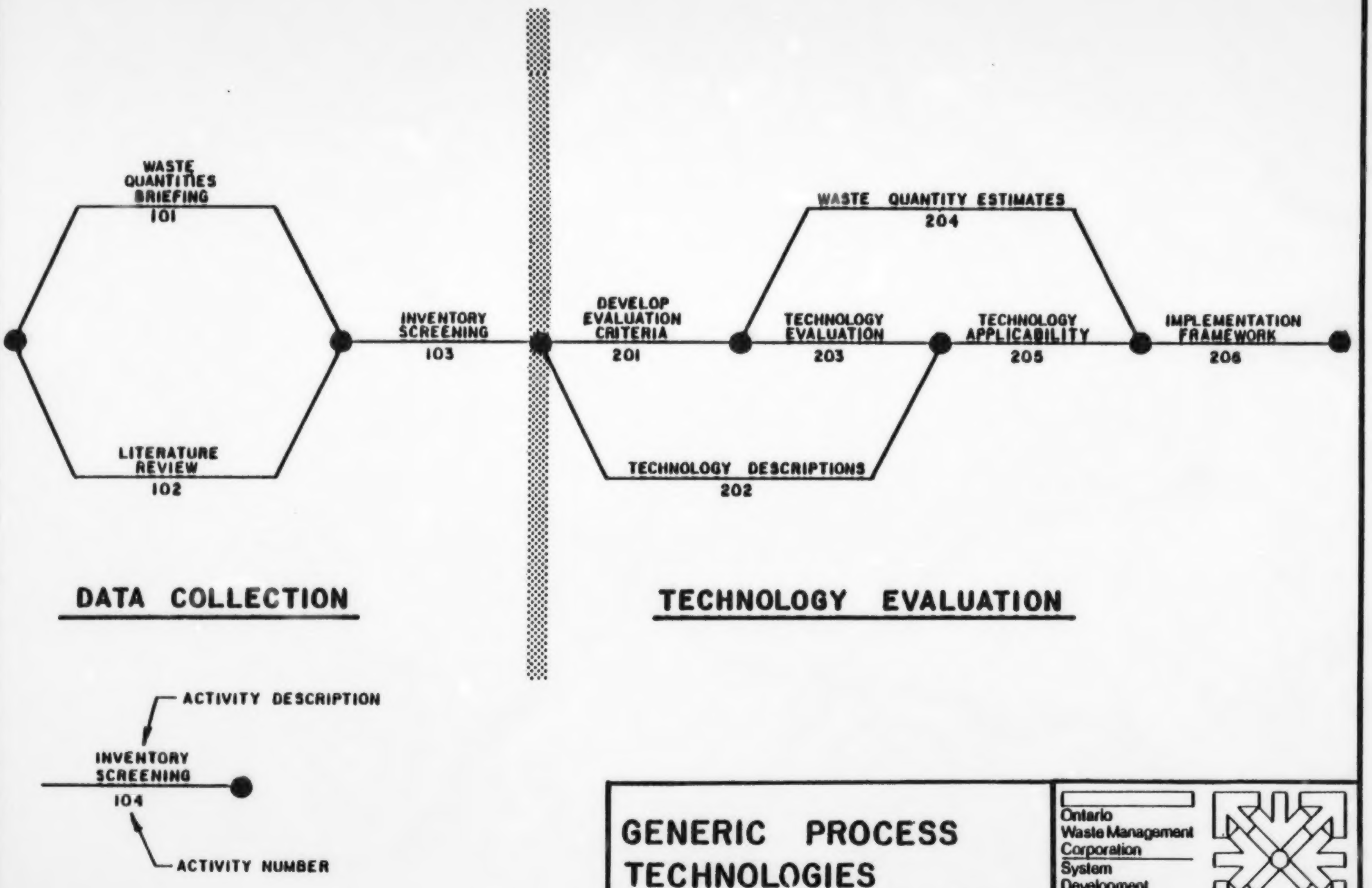
W

WASTE EXCHANGE System for hazardous waste information sharing between generators and other firms to facilitate the transfer of wastes to firms that can sue the wastes as raw materials. The Canadian Waste Materials Exchange operates a waste exchange throughout Canada including Ontario.

WASTE MANAGEMENT The total process of the collection of waste at its point of generation, transportation, treatment and final disposal in an acceptable manner.

WAYBILL SYSTEM Provincial, Federal or State procedures for tracking hazardous wastes from a generator, through a transporter, to a facility using shipping documents which msut be signed at each management stem and then filed with the proper regulatory agency. The Regulation governing transfers of liquid industrial waste is Ontario Regulation 926/76.

APPENDIX C


WASTE QUANTITIES BRIEFING
101
LITERATURE REVIEW
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204
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205
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206
DATA COLLECTION
TECHNOLOGY EVALUATION
ACTIVITY DESCRIPTION
INVENTORY SCREENING
104
ACTIVITY NUMBER

GENERIC PROCESS TECHNOLOGIES STUDY METHODOLOGY

FIGURE C -1 JULY, 1982

Ontario
Waste Management
Corporation
System
Development
Project

The Proctor & Redfern Group

APPENDIX D

FURTHER READING

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